Appendix A

Appendix A-1: Region V State Monitoring & Assessment Program Interviews: Annotated List of Discussion Topics

Appendix A-2: General Overview of Region V State Basin Assessment Designs

Appendix A-3: State Monitoring and Assessment Programs: Preferred Design and Indicator Options

Appendix A-1

Region V State Monitoring & Assessment Program Interviews: Annotated List of Discussion Topics

Introduction

The Midwest Biodiversity Institute (MBI) has been tasked by U.S. EPA, Region V to conduct an assessment of the Region V State bioassessment and ambient monitoring programs with emphasis on how data and information are used in support of various aspects of water quality management. In order to accomplish this task, MBI is conducting detailed interviews of key program State program managers and staff in order to understand the extent of data-driven water quality management, where it exists. We are using these interviews as an opportunity to better define and understand the uses of monitoring and assessment information in each State and determine the opportunities, incentives, impediments, and barriers to the fuller use of this information in support of water quality management programs. MBI will be preparing a report based, in part, on these interviews and additional information that is available which describes the State's use of monitoring and assessment information.

Who Should Attend

The evaluation of each State program is focused on current and planned uses of monitoring and assessment information in support of water quality management programs. This includes water quality standards (WQS), reporting and listing (305b, watershed assessments, 303d listings, TMDL development and implementation), planning, nonpoint source assessment and management, dredge and fill (404/401), and NPDES permitting as these represent the most in-common elements of State water quality management programs. Thus, managers and staff who can speak to the operation and management of these programs should attend at least that portion of the interview.

The following topics are intended to generally outline the interview process and ensuing discussion of each topic. These are intended to guide the interview and serve as a guide for State preparations for the discussions. Each interview is intended to occupy one and one-half days. Day one will focus on the use of monitoring and assessment information to support water quality management and the second one-half day will focus on specific bioassessment issues.

Day One: The Use of Monitoring and Assessment Information in Support of Water Quality Management

Monitoring and Assessment Program

In terms of achieving the goal of supporting water quality management with indicators of environmental exposure and response, the State's monitoring and assessment program is vital to achieving that goal. Monitoring includes the systematic collection of chemical, physical, and biological data in the ambient environment. Assessment includes the analysis and transformation of that data into meaningful assessments that include attainment/non-attainment determinations, characterization of impairments (extent and severity), associations between impaired states and causes (i.e., agents) and sources (i.e., activity or origin), and providing data and information to develop improved tools, indicators, criteria, and policies. This process then supports reporting that is required by the Clean Water Act (305[b], 303[d], 319, etc.) and that used by the State for allied purposes (watershed assessments, site-specific assessments, planning, TMDL development, etc.).

Monitoring &Assessment Topics

1. Spatial design:
   - Rotating basin approach (sequence and cycle; linkages to management. activities)
   - Probability-based
   - Fixed station
   - Resource types (wadeable streams, large rivers, great rivers, lakes, wetlands, headwater streams, etc.)
2. Basin assessments:
   - Scale (major basin, subbasin, watershed, subwatershed)
   - Site-selection – targeted, random, other
   - Site density (how many sites sampled in a study area)
   - Stratifying factors (watershed area, stream order, other)
   - Number of sites, surveys each year
   - Data analysis and reporting sequence
   - Bottlenecks in data analysis and reporting?
   - Logistical issues
   - Study planning process – are different disciplines integrated?
3. Index Periods:
   - Seasonal sampling index periods (summer-fall, monthly, other).
   - Flow attenuated considerations (loading estimates, event related)
4. Chemical/physical assessment:
   - Media (water, sediment, tissues, etc.)
   - Purpose of sampling (ambient characterization, model calibration, long term trends, reference/background, etc.)
   - Parameter groups, how selected
   - Laboratory support
   - Sampling design and logistics (survey design, frequency, grabs vs. composites)
   - Exceedence issues (magnitude, duration, frequency)
5. Resources:
   - FTEs devoted to M&A by discipline (chemical/physical, biological assessment, TMDL/modeling, etc.)
   - Proportion of FTEs devoted to water quality management programs (please provide a table of organization)

- Funding sources and limitations
- Cost determinations
- Are current resources adequate? if not, what is needed?

6. Reference Condition
   - Have reference sites been established? For what purposes (biocriteria, nutrients, background conditions, etc.)
   - How many reference sites?
   - Spatial organization and stratification (ecoregions, hydrologic units, physiographic regions, other)
   - How is reference determined (data driven, cultural, least impacted)?
7. Data processing and management
   - How is data stored (STORET, other system)
   - How is data accessed for analysis?
   - Resources dedicated to data management
   - QA/QC procedures for ensuring data quality
   - Timetable for entry and validation
   - Ease of availability within and outside agency
   - Demand for data from outside agency
8. Monitoring Strategy
   - Latest update available (please provide a copy)
   - Is it a useful document?
   - Should the strategy serve as a documentation of data acceptability?
   - Are data quality objectives defined?
   - Frequency of update.

Reporting and Listing (305b/303d)

Reporting and listing here refers to the process of producing the biennial 305b report and the 303d list of impaired waters, both of which have received greater emphasis during the past decade. The information contained in these reports and lists are not only important to determining the effectiveness of a State's water quality management efforts, but are increasingly being used to set program priorities and allocate funding (i.e., Section 106 allocations). Monitoring and assessment information is an indispensable element of this process and how it is generated and used determines, in part, the accuracy of the statistics that are reported via 305b and 303d. Thus, it is important to determine and understand the process used by each State.

1. Delineation of impaired/threatened waters
   - Procedures, protocols for determining extent and severity of impaired waters – arbiters of impairment and threat.
   - Monitored, evaluated, survey assessment hierarchy?
   - Extent of extrapolation from single or aggregate sampling sites, how was this developed and has it been tested?
   - Which uses are reported?

- Aquatic life impairment – based on which data (biological, chemical/physical, mix of both, best professional judgment, etc.)
- Determination of causes and sources of impairment and threat – is this always linked to an impairment or threat?
- Determination of severity, extent, incremental changes
- Any impact or implications from 106 allocation formula (based on impairment information)?
- Universe of resource definition (miles of rivers and streams, lake acres, etc.)
- Do we need to assess 100% of all resources? Would better targeted subsets serve as well?

2. Assessment process
    - "Chain-of-custody", i.e., do the same staff who collect and analyze sampling data produce the assessments?
    - Volunteer organization data – how used? "admission" requirements? any testing of accuracy? pressure to accept data?
    - Other organization data – acceptance requirements?
    - Credible data legislation? proponents, agency position
3. 305b Report
    - Trend assessment – tracking of aggregate condition through time, by resource type, designated uses, etc.
    - Extent of use by agency to guide water quality management – is it viewed by management as a report card? other value? does it distinguish impairment by point and nonpoint sources? subsets within each?
    - Extent of use by outside groups
    - What would impact of changes in statistics be?
4. 303d/TMDLs
    - Relationship between 305b report and 303d list – conversion process, issues, concerns, gaps and shortfalls
    - Should 303d be aligned with 305b?
    - Influence of EPA's CALM guidance
    - Is TMDL development coordinated or aligned with ambient monitoring and assessment?
    - Use of biological data in TMDL process – for? opposed? issues and concerns
    - Ramifications of listing beyond TMDL development (additional implications, perceptions of liability, etc.)
    - Are there sufficient tools available to develop defensible TMDLs that will contribute to restoration of impaired uses? What is needed and how long will it take?
    - What are important underlying components of the TMDL process? Are these sufficient?
    - Is there sufficient data available to develop TMDLs? what's missing?

Water Quality Standards

Water quality standards provide the basis for water quality management in terms of benchmarks and criteria for designing management programs and judging the effectiveness of those programs. Of interest to the interview is the recent emphasis by EPA on refined aquatic life uses and biological criteria. Thus, the following topics emphasize this part of the WQS process.

1. General WQS Issues:
   - Describe the structure of the State's WQS – designated uses, criteria, and antidegradation policy.
   - How are chemical WQ criteria derived? any modifiers or adjustment factors?
   - Any special WQS application language?
   - Existing use issue – what is the State's view? how is it determined?
   - Site-specific criteria issues? dealt with? how many?
   - How would better M&A help the WQS process?
   - Is rulemaking an issue, i.e., burdensome, difficult, risk of unintended outcomes?
2. Designated uses
   - Description of designated uses in the State WQS (a copy of the relevant parts of the WQS is requested)
   - Are individual waters designated? default uses? other?
   - What triggers individual designations? are they downgrades? does anything trigger an upgrade? is there a regular process for inventorying these needs?
   - Less than CWA goal uses? how defined?
   - EPA ALUS process – familiarity with?
   - Level of interest in refined uses (advantages, disadvantages, barriers to development and implementation)
3. Use Attainability Analysis (UAAs)
   - Experience with UAAs (number, problems, issues)
   - Outline/describe UAA process – is it a routine? special project oriented? what triggers a UAA? what are preferred data and information requirements?
   - Stakeholder perceptions of UAA process (pro and con, requests, etc.)
   - Has the emphasis on 303d listing increased the interest in UAAs?
   - Are UAAs seen as an "easy" exit off of the 303d list?
   - Attainability issue – can a water be impaired in perpetuity? criteria for determining attainable use.
   - What are some specific attainability issues? urban? agricultural? other?
4. Biological Criteria:
   - Have biocriteria been adopted or proposed (narrative, numeric)?
   - Impact of EPA's Policy of Independent Application
   - Linkage to designated uses – pros and cons
   - Impact of EPA ALUS model and refined use initiative
   - Advantages, disadvantages of biocriteria in WQS, in-house barriers?

- Would biocriteria force reconsideration of any "downgrades" or any other revisions to uses?
- Habitat criteria?
- Stakeholder perceptions and views

Assessment Integration Issues

The integration of monitoring and assessment information within water quality management programs is an important and emerging issue and ultimately fulfills one of its most important purposes. Region 5 is working with the States to develop a set of shared environmental goals and milestones. This will partially fulfill efforts to implement the National Environmental Performance Partnership System (NEPPS), which promotes joint priority setting and planning through the increased use of environmental goals and indicators. The shared goals and milestones will be used to more comprehensively report to the public and environmental decision-makers about the status of water resources in the Region and document progress to meeting these goals. The goals and milestones will also be used to more effectively target programmatic efforts at the national, state, and local levels. It is important that we are able to document achievements so that our environmental successes are recognized, funding is maintained at appropriate levels, and effective management programs continue to be implemented. The following are aimed at assessing the State's efforts to develop and use indicators and integrate them into water quality management.

1. Indicators for Surface Waters
   - Describe any efforts to develop a process for using environmental indicators to fulfill the role as a measure of the effectiveness of water quality management programs (provide any documentation)
   - Are any implemented or practiced?
   - How dependent are these systems on monitoring data?
   - What is the awareness of past EPA indicator development efforts, i.e., national indicators for surface waters, hierarchy of indicators, etc.
   - Is there any recognition of indicator roles (i.e., EMAP stress, exposure, response paradigm)?
   - What is (are) the most important measure(s) or indicator(s) of water quality management program success in your program? why?
2. Program Integration
   - Cite any examples in which water quality management programs rely on ambient monitoring and assessment information
   - Is monitoring and assessment information used to support the NPDES permitting process? 404/401 process? stormwater phase I or II? 319/NPS planning and implementation? brownfields? other?
   - How is monitoring and assessment information and resulting assessments, reports, etc. regarded by the above programs (essential, useful, nice to have, inconsequential)?

3. Training
   - Are training opportunities afforded staff and/or management?
   - How do these relate to indicators development, monitoring and assessment, biological assessment, or ecological principles in general?
   - Requests for field demonstrations (fish, bugs, sampling, etc.) for internal and external purposes

Other Information
The results of the interview process will provide important information for a report that will be submitted to Region V. This report will summarize the issues facing each State in reaching the goal of increased usage of ambient monitoring and assessment information to support water quality management. The State is encouraged to provide any documents or information that they feel would be useful in generating a fair and accurate summary of the interview process and the status of the use of monitoring and assessment information in water quality management. Follow-ups with each State will take place as the report is developed.

Day Two: Review of the State's Biological Monitoring and Assessment Program

Each State should have received and completed the questionnaire in support of U.S. EPA's *Update of State Bioassessment Programs: Success of EPA's Technical Transfer Efforts and Building State Capacity.* This portion of the interview process will focus primarily on the topics covered by the questionnaire and will afford an opportunity to provide important details and context that could not be communicated in that format. Again, the State is requested to provide copies of program documentation and any examples of outputs (reports, etc.) that characterize the current usage of biological assessments and criteria.

1. Biological Assessment Procedures (by assemblage)
   - Methods, field procedures
   - Lab procedures and logistics
   - Independent methods development
   - Field crew composition and deployment
   - Field logistics (time spent per site, travel, work week, etc.)
2. Sampling History
   - Number of sites, samples/year
   - Purpose (watershed assessments, special studies, site assessments)
   - Applied research and support (examples of each)
3. Facilities (lab/facility) tour and evaluation
   - Sampling equipment
   - Laboratory process, logistics
   - Training and qualifications

Appendix A-2

General Overview of Region V State Basin Assessment Designs

The following is a brief description of the overall monitoring and assessment designs employed by each of the six Region V states. This information was compiled from notes taken during the interview process and from the various documents provided about each State program. It is possible that changes have taken place or been initiated by the states since the January 2002 interviews. In addition, the following do not cover all of the monitoring and assessment activities that are conducted by the state. Therefore, each state's web site should be accessed for more detailed and current information.

Illinois
Illinois operates a monitoring design, which includes approximately 500 targeted sites allocated among 33 major basins. Approximately one-fifth of these sites (81-114/year) are sampled each year for fish and macroinvertebrates. These are further targeted at order 4 streams where perennial flow is likely to be maintained. No trends in biological condition are reported, but IEPA expects this will be forthcoming when sufficient data is collected and assessed.
http://www.epa.state.il.us/water/water-quality/monitoring-strategy/index.html

Indiana
Indiana employs a 5-year rotating basin approach in which the entire state is covered in that time period. This is accomplished by using a probability design within each of five major aggregations of river basins in Indiana. Approximately 50 macroinvertebrate and fish sites are randomly selected from 1-4 order streams. No trend assessment is performed, but IDEM expects this to be forthcoming once the basin process matures.
http://www.in.gov/idem/water/planbr/wqs/quality.html

Michigan
As of 1997, Michigan visited 200 wadeable stream sites per year representing 2.5 percent of the state's wadeable stream miles. By 2001, approximately 700 macroinvertebrate samples per year are being collected from 80% of the wadeable streams in each basin. Sampling sites are selected using a targeted approach and consider the complexity of the study area and the landscape setting. The information from these surveys is used to support selected water quality management actions including NPDES permit reissuance, the cycle of which was reconciled to basin monitoring in 1983. MDEQ expects that trends in biological resource condition will be forthcoming once the basin assessment process matures.
http://www.michigan.gov/deq/0,1607,7-135-3313_3686_3728--,00.html

Minnesota
Minnesota recently implemented a rotating basin approach with the goal of assessing the entire state by 2015. Sampling is conducted in each of 10 major basins over a 2-year period with an additional year of follow-up sampling. Biological assessments include both fish

and macroinvertebrates at both targeted and randomly selected wadeable stream locations. Approximately 125-150 targeted sites and 50 probability sites are located in each basin area. The purposes of the targeted sites are to provide reference data for the development of biocriteria and other assessment criteria and a dataset over a gradient of different disturbance types and impacts. Stratifying factors include ecoregions and subregions and watershed area. MPCA expects that this design will yield information about trends in the future as the basin cycle process matures. No trend reporting on biological resources takes place at this time.
http://www.pca.state.mn.us/monitoring/index.html

Ohio
Ohio has employed a rotating basin approach since the early 1980s. Fish and macroinvertebrates are sampled at approximately 500 targeted sites within 3-4 basin areas each year. Ohio has 23 major basins and 93 subbasins, which are used to conduct and plan the basin approach. A geometric site-selection process has been used since 1998 in an effort to pre-assess subbasins targeted for TMDL development. The information from this monitoring design directly supports all water quality management programs including water quality standards, NPDES permitting, TMDLs, nonpoint sources, planning, and specific local and watershed issues. This database has provided information to support detailed trend assessment and forecast analyses in the 305b report.
http://www.epa.state.oh.us/dsw/bioassess/ohstrat.html

Wisconsin
Wisconsin has essentially operated a rotating basin approach within a basin planning process since the mid-1980s. In the mid-1990s, a more focused approach was organized within the 23 major geographic management units (GMU) developed by WDNR. Approximately 20 sites are sampled for fish and macroinvertebrates within each GMU. Sites are targeted and are aimed at specific management issues within each GMU. No trends are reported for biological resource condition.
http://www.dnr.state.wi.us/environmentprotect/water.html

Appendix A-3

State Monitoring and Assessment Programs: Preferred Design and Indicator Options

INTRODUCTION

The Midwest Biodiversity Institute (MBI) was requested by U.S. EPA, Region V to conduct an assessment of state surface water monitoring and biological assessment programs. This effort, in addition to the review accomplished by Region V as part of the CALM process, is intended to lead to improvements in surface water monitoring throughout Region V. A principal focus of this effort is in determining the spatial design(s) and environmental indicators that will serve to make more effective use of monitoring and assessment in support of *all relevant aspects of water quality management.* As such this appendix focuses on; 1) communicating the essential underlying concepts and principles of a comprehensive and adequate monitoring and assessment program, 2) determining the design and indicator options available to the states and EPA, and 3) evaluating the advantages and applicability of each option.

This assessment is focused on current, planned, and potential uses of monitoring and assessment information in support of water quality management programs. These programs include water quality standards (WQS), reporting and listing (305b, watershed assessments, 303d listings, TMDL development and implementation), planning, nonpoint source assessment and management, dredge and fill (404/401), and NPDES permitting as these represent the most in-common elements of state water quality management programs. **It is a fundamental premise of this assessment that ambient monitoring and assessment should function to support *all* relevant water quality management programs in addition to its more commonplace role of supporting status assessments**. Determining the potential linkages to the state's water quality standards (WQS) and reporting (305b, 303d) obligations are especially emphasized, as these are fundamental to the broader use of environmental data in management decision-making. This is consistent with contemporary efforts to revitalize and improve the use of environmental data in management decision-making (ITFM 1992, 1995; U.S. EPA 1995a,b; Yoder 1998; NRC 2000; NRC 2001; The Heinz Center 2002) and emerging efforts at EPA to more effectively translate environmental data and indicators to defensible criteria and standards (e.g., refined aquatic life uses, biological criteria development and implementation, EPA's Consolidated Assessment and Listing Methodology [CALM] process).

This review is focused primarily on the assessment of aquatic life in the lotic (flowing) freshwaters of Region V. The lentic (standing open waters), wetland, and primary headwater ecotypes are also important resources and many of the essential concepts and principles discussed here are applicable to these systems. Obviously, there will be different indicators and designs that better suit the needs of assessing and managing these ecosystems and some are being developed, at least conceptually, through ongoing efforts. This assessment emphasizes aquatic life related issues and concerns since these frequently determine water quality management needs and policies in freshwater systems. Aquatic life uses apply to all jurisdictional water bodies, thus it is a universally relevant water quality management issue. It also requires a deliberate stratification process including attention to watershed size (i.e., headwater, wadeable, non-wadeable), ecotype (i.e., cold water, warmwater, coastal plain), and appropriate ecological indicator assemblages (i.e., fish, macroinvertebrates, algae). Co-occurring concerns such as water supply, human and wildlife health, and recreational uses that must also be supported by adequate monitoring and assessment are recognized and these can be addressed as overlapping concerns. However, programs that incorporate the underlying concepts and principles which support more detailed definitions of aquatic resource types and refined uses for aquatic life are better able to transfer the conceptual underpinnings and the improved technology this fosters to other water uses and concerns; hence the emphasis on aquatic life and ecological assessment. This approach can provide the type of informational feedback that fosters a more integrated and interdisciplinary approach to water quality management.

The Relationship Between Monitoring and Watershed Management

There is abundant evidence and a growing appreciation that our air, land, and water resources are subject to a wide variety of effects from human activities on local, regional, national, and global scales. However, the mere recognition that these effects occur, that many are potentially detrimental, and some can be addressed through prescriptive management programs is simply insufficient. The ability to measure the extent and severity of these effects and further understand their causes and origins is needed to construct accurate, effective, and proportionate management responses. Simply put, adequate monitoring and assessment is the key to enabling this process. Some estimate that upwards of $500 billion to $1 trillion have been spent on water pollution abatement nationally since the Clean Water Act revisions of the early 1970s. Yet, with only a few exceptions, the effectiveness of these expenditures has not been consistently nor accurately documented in environmental terms (GAO 1986; 2003a). One reason may lay in the fact that only 0.2% of the amount spent on water pollution abatement was devoted to ambient monitoring in the 1970s and 1980s (ITFM 1992). Federal and state agencies during that time period were primarily focused on regulatory and pollution source abatement - adequately documenting the effectiveness of those activities was not a significant part of the process.

Few, if any, state monitoring programs were sufficiently funded, developed, or designed to deliver an accounting of environmental results on a systematic basis. Simply put, state and federal agencies were neither equipped nor motivated to develop the types of monitoring and assessment efforts that were needed to both assess and guide water quality management. Inevitable questions about the results of the large expenditures of public and private funds could not be satisfactorily answered by most state and federal agencies, a situation that persists into the present (National Research Council 2001; GAO 2003a). This resulted in a number of efforts to revitalize environmental monitoring at the federal level, the most noteworthy of which was the Intergovernmental Task Force on Monitoring Water Quality (ITFM 1992, 1993, 1995). When coupled with the technical developments in sampling methods, indicators, data management, and assessment tools that occurred during the same period, this delivered the type of process that was needed earlier. However, progress in reaching the goal of adequacy (Yoder 1998) requires several years to accomplish. This task was forced to compete with other water program priorities and crises, some of which were an outcome of a lack of adequate monitoring and assessment (i.e., the TMDL process) hence progress has been incomplete. The challenge of adequately and consistently measuring, characterizing, and understanding the significance of environmental impacts has been met in only a few instances. Having such a capacity is crucial to the effective management and protection of water resources within state water quality management programs. Adequate monitoring and assessment is an indispensable component of achieving this goal (ITFM 1992, 1995; Yoder 1998; NRC 2001).

A major problem in promoting the wider usage of monitoring and assessment information to guide water quality management is the legacy of assessing the effectiveness of these programs based on administrative activities termed here as "outputs". This situation exists despite the repeated calls of national compendia (e.g., ITFM 1992, 1995) and panels (NRC 2001; The Heinz Center 2002; GAO 2000, 2003a,b) to strengthen and increase the use of environmental measures, or "end outcomes". Monitoring has for too long been viewed as an analog of the radar "gun" used to identify speeders - it detects when environmental criteria are exceeded. While important for that purpose, monitoring serves other needs as well (Karr 1991; Karr and Chu 1999): diagnosing the causes of degradation, evaluating restoration efforts (Yoder 1998; Yoder and Rankin 1998), and providing information on status and trends about the "infrastructure" of the aquatic environment. state water quality management agencies should devote as much effort to tracking resource condition as to enforcing compliance. Today, the latter function dominates at the expense of former, and little has been accomplished towards integrating the two tasks.

The U.S. General Accounting Office (GAO 2003a) notes that a primary dependence on administrative performance measures (e.g., number of environmental standards established, permits issued, and enforcement actions taken, all referred to as *outputs*) still limits evaluations of program effectiveness, including EPA's ability to assess risk. In 1999, for example, 86% of 278 performance measures listed by U.S. EPA were *outputs* rather than *end outcomes* (measures that directly measure environmental conditions). The proportion of environmental performance measures increased from 7% in 1999 to 27% in 2003. But even so, most of the end outcomes are for individual chemical pollutants, not more comprehensive biological responses. If states are to heed the calls for a more environmental results driven process of measuring program performance, then adequate monitoring and assessment must become a real priority for water quality management programs. The urgent need is to have adequate environmental information routinely available so that agencies and stakeholders will embrace it as a fundamental need and priority that is equal in importance to administrative programs and outputs. A significant problem with many of the recent environmental indicators initiatives is that they have resulted mostly in a compilation of lists of different indicators, sometimes without regard to their appropriate roles and/or without a systematic process for evaluating their meaning. A companion process to label indicators in accordance with their most appropriate roles (Yoder and Rankin 1998) and a systematic process for integrating the different indicators (U.S. EPA 1990, 1995a) is also required to ensure quality assessment products. This companion process has not been adequately linked to indicator development and use in most cases. An important goal for EPA and the states should be to have the effectiveness of administrative actions determined by environmental *end outcomes* as measured by the information and indicators gained from adequate monitoring and assessment. Inherently embedded in achieving this goal is the adequacy of other essential components of water quality management infrastructure including water quality standards (WQS).

Why is all of this important? One reason is to avoid the unnecessary propagation of assessment error, i.e., incorrectly designating waters as impaired when they are not (type I error) or failing to detect degradation and impairment at all (type II error). Common sources of type I and II errors include improper stratification of ecological potential across regional landscapes (e.g., not incorporating the influence of stream size) or poorly developed or improperly selected indicators of water body condition (Karr and Yoder 2004). For aquatic life uses, assessments may reach substantially different conclusions if based on chemical sampling versus biological assessments. Poorly conceived and implemented biological indicators can lead to similar errors. Type I errors receive substantially more attention (NRC 2001) because of their visibility to stakeholders. Type II errors may receive little or no notice, despite this being the predominant assessment error in many places (Karr and Yoder 2004). The adequate monitoring framework envisioned by this strategy should lead to a minimization of both types of assessment error.

More is at stake than incorrectly designating the status of water bodies and includes the identification of the causes and sources that are associated with observed impairments. Again, adequate indicators and assessment design is equally important in ensuring desirable outcomes in the assessment process. The ignorance or underrating of important degradation agents (altered flows, changes in physical habitat, adverse effects associated with invasive alien taxa, and so on; NRC 2001) is a problem when assessments rely on narrowly focused concepts and indicators. The TMDL process in particular emphasizes a small set of individual pollutants (the top five are sediment, pathogens, metals, nutrients, and organic enrichment; GAO 2003b) while many serious pollutants and forms of pollution, not to mention important interactions among them, go unrecognized (Karr and Yoder 2004). *Pollutants* are substances added to waters by human activity [CWA section 502(6)]. The Clean Water Act further defines *pollution* as human-induced alteration of waters caused by pollutants as well as non-pollutant agents, such as flow alteration, degradation of riparian zones, physical habitat alterations, and invasive alien taxa [CWA section 502(19)]. An adequate approach to monitoring and assessment is needed to ensure that significant limiting factors are not overlooked.

Intergovernmental Task Force on Monitoring Water Quality (ITFM)

Improving monitoring in the states requires a strategy that has generally been outlined by the ITFM process and federal 106 monitoring guidance (U.S.EPA 1994). The following represent the key principles of adequate monitoring and assessment as articulated by the ITFM (1995). Accordingly, water monitoring has four major aspects:

Context: Monitoring should be the foundation of water resource policy-making and management. This means that monitoring information should not only be available to managers and policy makers, but also be sufficiently comprehensible and conclusive. A critical aspect is not just providing data and information, but an assessment of what that information means. This includes a determination of whether or not important criteria, standards, and other management requirements are being achieved and the degree (both quantitatively and qualitatively) to which any are being exceeded or abrogated. This process requires the use of multiple classes of indicators, each functioning within their most appropriate roles (Yoder and Rankin 1998) and in their proper relationships to each other.

Scope: Monitoring includes the following activities: articulating objectives; collecting, storing, and interpreting data; conversion of data to information; preparing assessments of the information (conveying its meaning); communication of assessment results; and evaluation of management program performance. This organization allows water quality management programs to become more appropriately focused on the resource at issue, as opposed to an emphasis on the care taking of administrative systems and processes. This fosters an approach of managing for results in the environment where administrative processes are tools to improve the environment, not an exclusive endpoint of water quality management.

Scale: Monitoring includes all relevant scales such as site-specific investigations, regional descriptions and comparisons, and statewide summaries at various temporal scales. State monitoring strategies need to be constructed so that the same basic core data supports assessments at all of these scales. The specific designs, indicators, and assessment tools used must be tailored to the regional peculiarities in climate, soils, land use, geology, ecological resources, socioeconomic influences, and geography. Thus the indicators that are used need to be sufficiently developed and calibrated to reflect these influences and the scales at which the monitoring program must operate. This also means that monitoring and assessment must be designed to address objectives other than status and trends, which means assessing at the same resolution, i.e., at the same spatial and temporal scale at which water quality management is being applied. Failure to reconcile the scale issue risks "disconnecting" the results of water quality management from the validation of adequate monitoring. This would also call into question claims of environmental improvement or problems based on administrative measures alone.

Objectives: Generally, monitoring program objectives include: 1) determining status and trends; 2) identification of existing and emerging problems; 3) support of water quality management policy and program development; 4) evaluating program effectiveness; 5) responding to emergencies, and 6) continued development and improvement of the understanding of the basic chemical, physical, and biological processes that affect environmental quality. Achieving all of these objectives requires not only adequate monitoring and assessment, but also full integration of the results into the details of each management program.

Effective monitoring and, by extension, water quality management, requires a sufficient infrastructure and capacity in terms of personnel, facilities, and logistical support to carry out monitoring from a "cost-of-doing-business" standpoint. Initial estimates of the proportion of a state water quality management program that should be dedicated to monitoring and assessment activities ranges from 15-20% in terms of staffing and funding (although this may vary from place to place). This also includes an equitable distribution of effort between chemical/physical and biological assessments and monitoring aimed at watershed scale assessment and planning in addition to the determination of status and trends. More precisely quantifying these needs is an important goal of ongoing efforts to more thoroughly analyze state programs in the Regions and across the U.S.

U.S. EPA Section 106/604(b) Monitoring Guidance
Revised monitoring guidance issued under sections 106 and 604(b) of the Clean Water Act became available in October 1994 (U.S. EPA 1994) following a lengthy review process. This, too, was largely an outgrowth of the ITFM process. The 1994 strategy lists five key objectives for surface water monitoring programs:

1) identification of impaired waters throughout the U.S.;
2) increasing the number of waters assessed (i.e., miles, acres, etc.) by utilizing cost-effective techniques and methods appropriate to the condition of and goals for specific water bodies;
3) achieving greater comparability in parameters and methods to enable improved data sharing and geographical comparability;
4) using in-common indicators to report on the condition of the nation's waters; and,
5) improving information sharing with both public and private organizations and in the context of watersheds.

These were further allied with the theme of revitalizing state monitoring programs and reporting core information in a comparable manner.

The overall goal of the 106/604(b) strategy is to develop and implement a surface and ground water monitoring strategy to help achieve the goals and objectives of the Clean Water Act (CWA) and related environmental initiatives. This requires the use of a mix of approaches that provide for the design, collection, measurement, storage, retrieval, assessment, and biological/ecological data necessary to efficiently and effectively meet the objectives of the CWA.

An acceptable monitoring strategy includes the following purposes:

1) determining status and trends;
2) identifying causes and sources of impairment and threats and ranking in priority order;
3) designing and implementing water quality management programs;
4) determining program effectiveness; and,
5) responding to emergencies.

Implementing a monitoring strategy consistent with these purposes in Rhode Island should support the development and attainment of water quality standards (WQS), TMDL/303(d) listing and development, RIPDES permitting, nonpoint source assessment and management, watershed and ecosystem protection, and the development and use of environmental indicators.

Environmental Indicators for Surface Waters

An environmental indicator is defined as ". . . a measurable feature which singly or in combination provides managerially and scientifically useful evidence of ecosystem quality, or reliable evidence of trends in quality." (ITFM 1995) This definition generally provides some of the underlying ground rules by which environmental indicators should be developed and used. Indicators should not only have a firm basis in science, but also have relevance to management needs and uses. This includes being expressed or translated to terms that are commonly understood and comprehended by non-practitioners. Environmental indicators, when used within their most appropriate roles, provide the means by which water quality management programs can successfully link management actions to environmental results. This approach is most successful when direct measures (as opposed to surrogates) are used to determine the attainment of goals such as those embodied in the designated uses defined within state WQS (NRC 2001).

A vision for environmental indicators can result in the institutionalization of indicator usage throughout the water quality management process. This should result in better environmental communication, forecasting, policymaking, program evaluation, and budget decisions. Furthermore, environmental indicators can become an integral component of environmental decision-making by supplementing administrative activity measures. Indicators have been accepted as objective measures of environmental quality, not necessarily as negative or positive sources of environmental information. However, to achieve the fuller use and integration of environmental indicators in accordance with the vision of having environmental measures drive management processes still requires some significant changes in which measures water quality management programs value as the most meaningful indications of overall success.

Consolidated Assessment and Listing Methodology (CALM) Process

In March 2003, U.S. EPA published *Elements of a State Water Monitoring and Assessment Program* (U.S. EPA 2003). Clean Water Act Section 106[e][1] and 40 CFR Part 35.168[a] provide that EPA award Section 106 funds to a state only if the state has provided for, or is carrying out as part of its program, the establishment and operation of appropriate devices, methods, systems, and procedures necessary to monitor and to compile and analyze data on the quality of navigable waters in the state, and provision for annually updating the data and including it in the Section 305[b] report. The *Elements* document recommends the basic elements of a state water monitoring program and serves as a tool to help EPA and the states determine whether a monitoring program meets the prerequisites of CWA Section 106[e][1]. This guidance is intended to provide a framework for states to clearly articulate their programmatic and resource needs and a reasonable time line for meeting those needs. EPA expects this effort will identify efficiencies to be gained through a holistic approach to program implementation. The *Elements* document further clarifies its intent as follows:

> "EPA and states need comprehensive water quality monitoring and assessment information on environmental conditions and changes over time to help set levels of protection in water quality standards and to identify problem areas that are emerging or that need additional regulatory and non-regulatory actions to support water quality management decisions such as TMDLs, NPDES permits, enforcement, and nonpoint source management. This information also informs EPA and state decision makers, the Congress, the public, and other stakeholders of the progress that the Agency and state partners are making in protecting human health and the environment. Without this information, it is difficult for EPA and the states to set priorities, evaluate the success of programs and

activities, and report on accomplishments in a credible and informed way (U.S. GAO 2000)."

As such, monitoring and assessment is clearly viewed as a program support function for all water quality management activities, not just reporting on status and trends.

EPA acknowledges that the variability in existing state programs is partially the result of requirements not being adequately articulated in the past. EPA also expects that state water monitoring programs will evolve over the next 10 years such that all states will have a common foundation in their monitoring programs that support state decision making needs. EPA expects that states will employ an iterative process to fully implement a monitoring program that reflects the *Elements* document, and will work with states to identify annual monitoring milestones. States should develop, over time, a monitoring program addressing the 10 elements summarized and described in the *Elements* document. The first of the elements is a long-term state monitoring strategy. This strategy will be state specific, be designed from the monitoring capabilities each state already has, and should include a timeline not to exceed 10 years to full implementation. EPA expects states to revise their monitoring strategies in FFY 2004 and begin to implement monitoring and assessment program improvements in FFY 2005.

The 10 elements are:

1) Monitoring strategy - a long-term and detailed implementation plan not to exceed ten years.
2) Monitoring Objectives – these are critical to the design of a monitoring program that is efficient and effective in generating data that serves management decision needs.
3) Monitoring Design - an approach and rationale for the selection of monitoring designs and sample sites that best serves the monitoring objectives.
4) Core and Supplemental Water Indicators - a tiered approach to monitoring that includes core indicators selected to represent each applicable designated use, plus supplemental indicators selected according to site-specific or project-specific decision criteria.
5) Quality Assurance - quality management plans and quality assurance program/project plans are established, maintained, and peer reviewed to ensure the scientific validity of monitoring and laboratory activities, and to ensure that state reporting requirements are met.
6) Data Management - an accessible electronic data system for water quality, fish tissue, toxicity, sediment chemistry, habitat, biological data, that timely data entry, data description, and public access standards.
7) Data Analysis and Assessment - methodologies for assessing attainment of water quality standards based on analysis of various types of data (chemical, physical, biological, land use) from various sources, for all waterbody types and all state waters are developed and used.
8) Reporting - timely and complete water quality reports and lists called for under Sections 305[b], 303[d], 314, and 319 of the Clean Water Act and Section 406 of the Beaches Act are published.

9) Programmatic Evaluation - the state, in consultation with its EPA Region, conducts periodic reviews of each aspect of its monitoring program to determine how well the program serves its water quality decision needs for all state waters, including all waterbody types.
10) General Support and Infrastructure Planning - the state identifies current and future resource needs it requires to fully implement the monitoring program strategy.

More detailed descriptions of each are available in the Elements document, which appears in Appendix C.

ADEQUATE MONITORING & ASSESSMENT

Some of the contemporary efforts to revitalize and better define the role of monitoring and assessment in state and federal programs (ITFM 1992, 1995; U.S. EPA 1994) and the emergence of workable, ecological indicator concepts (Karr and Dudley 1981; Karr et al. 1986) offer detailed frameworks that are the basis of what is termed here as "adequate" monitoring and assessment (Yoder 1998). The term "adequate" was deliberately chosen as a theme on which to base the template for evaluating individual state programs. It is an attempt to avoid usage of the term "minimum" which is what EPA has historically accepted. The term comprehensive was considered, although it can imply doing more than is necessary to achieve the basic goals and objectives outlined by the above referenced processes.

The baseline components of an adequate monitoring and assessment program were described in *Important Concepts and Elements of an Adequate State Watershed Monitoring and Assessment Program* (Yoder 1998; Appendix B). This document relied principally on the products and recommendations of the ITFM process, EPA's environmental indicators initiatives, and the experiences of selected states in operating consistent and adequately funded programs. In turn, these efforts have given critical foundational support to EPA's CALM process. It is important to recognize that achieving adequacy is about process as much as it is about data sufficiency. Successfully addressing the process issues are key to resolving the current deficiencies and inequities within and between state programs and questions about the reliability of state and national 305(b) reports and, by extension, 303(d) listings, nonpoint source and watershed management, and water quality standards.

This effort is intended to be complimentary with the goals of EPA's Comprehensive Assessment and Listing Methodology (CALM) process, which requires adherence to ten basic elements (U.S. EPA 2002). What is different here is the greater level of detail and specificity regarding specific roles and types of indicators and parameters and the tie-in to water quality standards, specifically designated uses and criteria. **It is a fundamental premise of this review that achieving the level of integration and detail implied by the contemporary efforts to improve and revitalize the role of ambient monitoring and assessment is contingent on actually executing an adequate approach to monitoring and assessment.** This includes the incorporation of essential, underlying concepts in addition to the *adequacy* of what is measured and monitored and over what spatial scales that it takes place. It also includes "infrastructure" issues such as staffing (including professional qualifications), facilities (e.g., laboratory, equipment, instrumentation), and support (e.g., data management, fiscal and administrative support).

Information from *adequate* monitoring and assessment is critical to the ability of the states and EPA to track, manage, and report on environmental quality and the important attributes that comprise and indicate that quality. Adequate information is needed to track trends and long-term patterns in environmental quality. It should be used to measure progress and decide where and how to focus water quality management resources. As such, adequate monitoring and assessment fulfills a key role in the management of surface water resources by driving the progression of events from initial problem identification and characterization through the making of management decisions in such areas as pollution abatement, planning, standards setting, and enforcement of laws and regulations. Just after passage of the 1972 CWA amendments, EPA regulations related the purposes of water monitoring directly to management goals and objectives (Figure 1). This provides a simple, yet comprehensive template on which the integration of monitoring and assessment and water quality management can be based.

Fundamental Objectives of Adequate Monitoring and Assessment Approaches

Function: Surface Water Assessment

- Collect and analyze baseline information.
- Establish cause/effect (causal associations).
- Compare results to criteria and goals (use attainment).
- Publish results - statewide, regional, site-specific.

Function: WQ Mgmt./Pollution Abatement

- Attainability analyses & criteria development (maintain WQS).
- Formulate/revise abatement strategies (TMDL development).
- Assess effectiveness of programs (WQ Management).

Function: Compliance Evaluation

- Monitor to determine compliance.
- Monitor to support enforcement.

after 40CFR Part 35

Figure 1. Objectives addressed by adequate monitoring and assessment programs (after 40 CFR Part 35).

An adequate monitoring and assessment framework includes not only what is measured, but also includes the spatial and temporal design of the data collection, the development of chemical, physical, and biological indicators, the processes used to assemble the data and information into meaningful assessments, and the organizational infrastructure within which it is accomplished. As such, this framework includes more than the mere collection of environmental data, but rather emphasizes the development of assessments based on that data. Guidance for developing an adequate monitoring and assessment process emanates primarily from the Intergovernmental Task Force on Monitoring Water Quality (ITFM) including their development of an integrated indicators framework (ITFM 1992) and a national strategy for water monitoring (ITFM 1995). This was followed by a description and outline of an adequate state watershed monitoring and assessment program by ASIWPCA and EPA (Yoder 1998). Simply stated, these latter efforts were aimed at not only revitalizing the role of monitoring and assessment in state and federal water quality management programs, but also accomplishing the long-held objective of integrating environmental information into management decision-making. This goes well beyond the often emphasized task of assessing status and trends in water quality nationwide and includes the much more difficult task of realizing integration with water quality management programs on a day-to-day basis. There are few examples of actually accomplishing a meaningful degree of integration. EPA and state water quality management programs are driven largely by administrative activities; their effectiveness are judged on the basis of administrative outputs (Figure 2). An important goal for EPA and the states should be to have the effectiveness of administrative programs determined by environmental *end outcomes* as measured by the information and indicators gained from adequate monitoring and assessment. Inherently embedded in achieving this goal is the adequacy of the essential components of water quality management infrastructure including water quality standards (WQS).

Key Concepts and Attributes

An important prerequisite to achieving an adequate monitoring and assessment approach is the incorporation of fundamental concepts in the development of the indicators and criteria that operationally determine the status of aquatic resources, designated uses, and the effectiveness of water quality management. These include a comprehensive approach to developing indicators and endpoints leading to the appropriately detailed and refined criteria and standards that guide management programs and measure their effectiveness. This approach addresses two of the principal issues identified by the National Research Council (NRC 2001) in their review of the role of science in the TMDL process; 1) adequate monitoring and assessment, and 2) appropriately refined and detailed water quality standards (WQS). Adequate monitoring includes the following key attributes and principles:

- Indicator development, position, and selection adhere to baseline theoretical concepts (i.e., Karr's five factors; NRC position of the standard [NRC 2001]);
- Use indicators that are cost-effective, yet comprehensive;
- Use indicators within their *most appropriate* roles (stress, exposure, or response);
- Indicators are directly tied to WQS via designated uses and numerical or narrative criteria;

Administrative Output vs. Resource Outcomes Based Management

	ADMINISTRATIVE OUTPUTS BASED	**RESOURCE END OUTCOMES BASED**
Goal:	**Program Performance** (Program execution)	**Environmental Performance** (Attain designated uses)
Measures:	**Administrative Actions** (Lists, Permits, Funding, Rules)	**Indicator End-points** (Biological, Chemical, Physical)
Results:	**Improve Programs** (Reduce backlogs, improve timeliness)	**Programs are Tools to Improve the Environment** (Admin. outputs evaluated by environmental end outcomes)

Figure 2. Administrative outputs and environmental end outcomes based water quality management. Adequate monitoring includes maturing towards an environmental end outcomes approach to water quality management.

- Measurement and data quality objectives (MQO/DQO) are defined by the WQS and are adequate to support accurate assessments and perform diagnostic functions;
- The program can adapt quickly to improved science and technology;
- The program is supported by adequate resources, facilities, and professionalism;
- The spatial design(s) matches the scale at which management is applied; and,
- The end product is an integrated assessment, not just the data.

Theoretical Concepts – Karr's Five Factors

One of the most important concepts developed over the past three decades is the recognition of how diverse human activities alter water resources and the extent to which those activities interact with topographical, geological, climatological, and biological differences among watersheds (Karr and Yoder 2004). Five features (or factors) of water resources that are altered by the cumulative effects of human activities (Figure 3; Karr et al. 1986; Karr 1991) are:

Energy source: includes changes in the food web including nutrients, organic material inputs, seasonal cycles, primary and secondary production, and sunlight.
Chemical variables: includes changes in chemical water quality including D.O., pH, turbidity, hardness, alkalinity, solubilities, adsorption, nutrients, organics, toxic substances, temperature, sediment, and their interactions.
Flow Regime: includes modification of flows including precipitation, seasonal patterns, land use, runoff, velocity, ground water, daily and seasonal extremes.
Habitat structure: includes alteration of physical habitat including bank stability, current, gradient, instream cover, vegetative canopy, substrate, current, sinuosity, width, depth, pool/riffle ratios, riparian and wetland vegetation, shorelines, sedimentation, channel morphology.
Biotic factors: includes changes in biotic interactions such as introductions of alien taxa, feeding, reproduction, predation, harvest practices and rates, diseases, parasitism, competition.

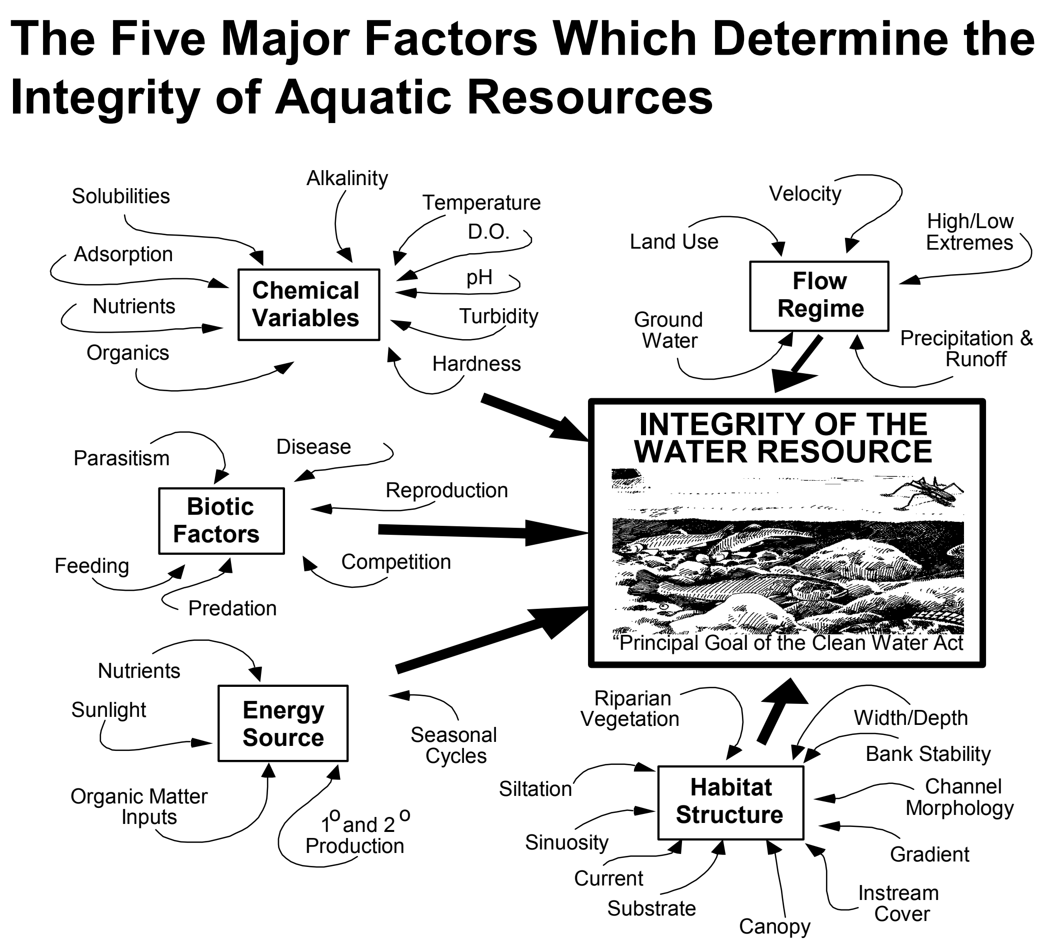


Figure 3. The five factors which determine the integrity of aquatic ecosystems with selected attributes of each (modified from Karr et al. 1986).

First, this model essentially defines the role and relevance of various chemical, physical, and biological attributes, some of which can be measured and used as indicators. It is the interaction of the attributes of the five features that produces the state or quality of a water resource. A measurable attribute of one of the five features by itself is seldom, if ever, a reliable indicator of the whole system or its state. However, measures that approximate the condition of the system as a whole are "positioned" closer to the endpoint of concern and hence function as more reliable indicators of condition (NRC 2001). Second, it provides a conceptual basis for choosing and using various chemical, physical, and biological indicators and measures within an adequate monitoring and assessment framework. An understanding of these interactions is an important guide to the selection of indicators for monitoring programs (Karr 1991; Yoder 1998). Third, it places biological measures in the role of an integrative response indicator that represents the synthesis of the interactions of the chemical, physical, and biotic attributes of a water resource. It provides a comprehensive signal to evaluate management actions that are inherently limited to measuring and controlling only *some* of the attributes. Lastly, it provides the basis for an additional model by which the sequence of stress and exposure can be validated by the observation of ecosystem response (Figure 4). Indicators of stress and exposure are routinely used in water quality management as design criteria and as compliance thresholds. Used alone, these may not achieve the desired result (i.e., restoration of an impaired designated use) or they may have unintended consequences, unless they are evaluated through the lens of biological response (Karr and Yoder 2004). It is the accurate measurement of biological response that is key to making this process work in actual practice, much more so than our ability to precisely measure stress or exposure. Stress and exposure criteria are determined through indirect means and as such function as surrogates for true biological response. This process offers a way to ground truth the application of water quality and other criteria in relation to the totality of the interactions that result in a biological response, but which cannot be accounted for on a parameter-by-parameter basis. Sequencing the management of stress through how it affects key attributes of the five factors through to the eventual biological response provides a process by which adequate monitoring and assessment can be used to validate the effectiveness of management actions to control stressors (Figure 4). The severity and degree of the biological response to these impacts is ultimately what is important, not the mere presence of an impact.

Cost-Effective Indicators

Cost-effective indicators are based on proven sampling methods and procedures that can be executed in a reasonable time frame and with reasonable effort. A commonly used description are measures that can be accomplished at a sampling site in a "few" hours, allowing several sites to be sampled each day, tens of sites per week, and hundreds of sites per year by a single field crew[1]. However, it includes indicators that are sufficiently developed, calibrated, and proven so as to ensure accuracy and precision. Accuracy includes the minimization of type I and II assessment error, i.e., the under or over estimation of status. It also includes the ability to extract meaningful diagnoses of observed responses using multiple chemical, physical, and biological parameters and measures, each used in their most appropriate roles as stressor, exposure, and response indicators.

[1] A field crew is a 2-4 person team dedicated to the collection of data for a specific indicator category (chemical, physical, biological).

Precision includes reliable estimates of chemical, physical, and ecological properties and that produce statistical rigor. Frequently, statistical rigor implies attention to sampling frequency and

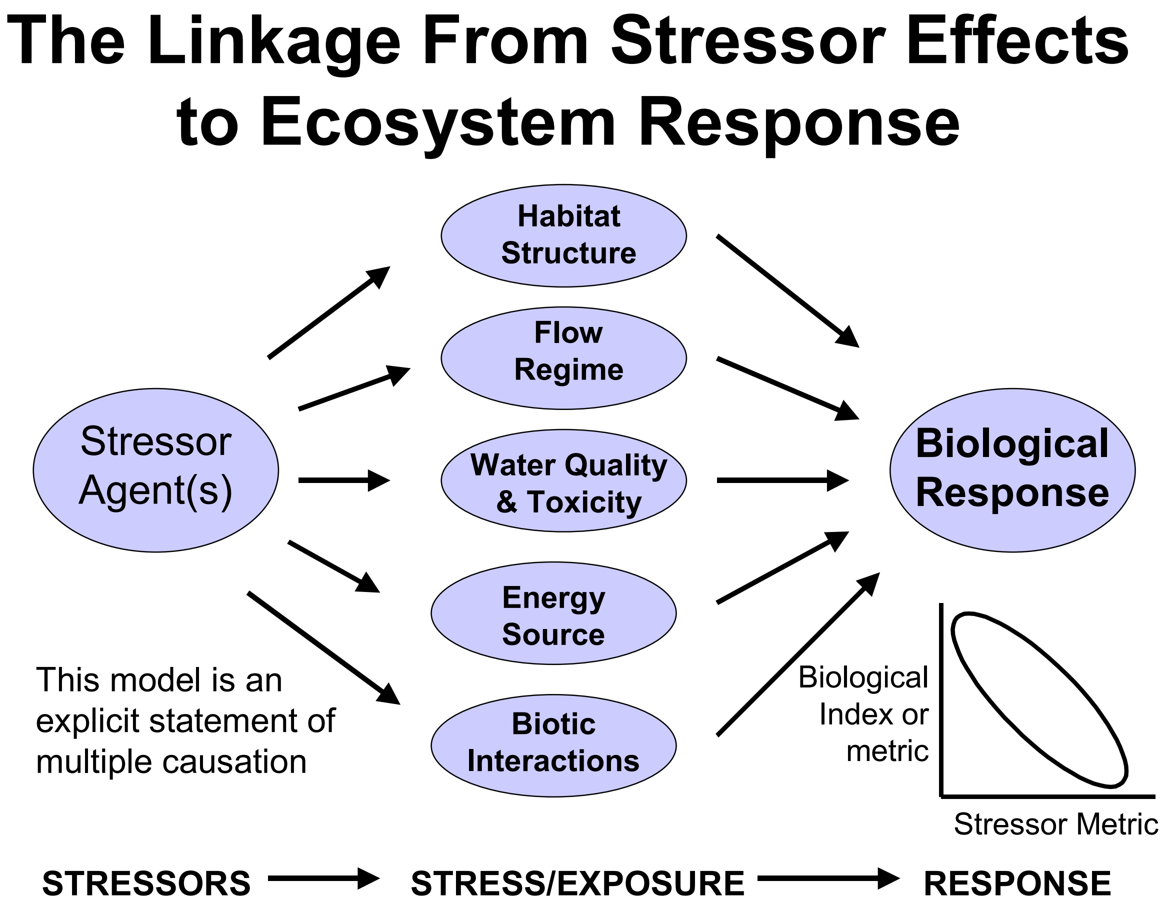


Figure 4. The linkage of the effect of stressors through Karr's five factors to the resultant biological response. The indicator roles represented by each category are identified in accordance with Yoder and Rankin (1998). After Karr and Yoder (2004).

reducing variance estimates. However, it is also important to understand the assessment capacity of each indicator and its position within the five factors that determine the integrity of a water resource (Figure 3). For aquatic life assessments, basing measures of condition on a biological indicator incurs the power of assessment inherent to the position of this indicator relative to the endpoint of concern, i.e., the health and well-being of the biota. Whereas attempting to estimate biological status using chemical or physical surrogates introduces the need to achieve statistically valid estimates for the parameter of concern, which may mean expending significant analytical and sampling resources. The use of the most direct measure of the endpoint of concern can in effect "leap frog" the statistical (i.e., sampling frequency) issues involved with surrogates and reduce the need for a higher degree statistical rigor for the surrogate indicator. In turn, the surrogates fulfill the role of stress and exposure indicators, which requires less statistical rigor and fewer samples. The trade-offs involved result in a more cost-effective monitoring and assessment program.

Another aspect of a cost-effective approach to monitoring and assessment is determining which indicators and parameters are measured in a given situation. The ITFM (1992) indicators process arranged indicators according to their role and value for first determining the state of the aquatic system and adding key parameters and indicators in accordance with specific designated uses and the complexity of the setting. The different types of measurements that comprise an adequate watershed monitoring and assessment approach consist of core and supplemental indicators and parameters (Figure 5). The **core** parameters are collected in *all* situations regardless of the assessment, regulatory, and management issues of concern. These represent the key, essential chemical, physical, and biological elements of water resource integrity (Karr et al. 1986) and reflect the most basic components of all aquatic ecosystems (living biota, habitat, and primary water quality). These fulfill the need to first characterize the condition and status of the baseline

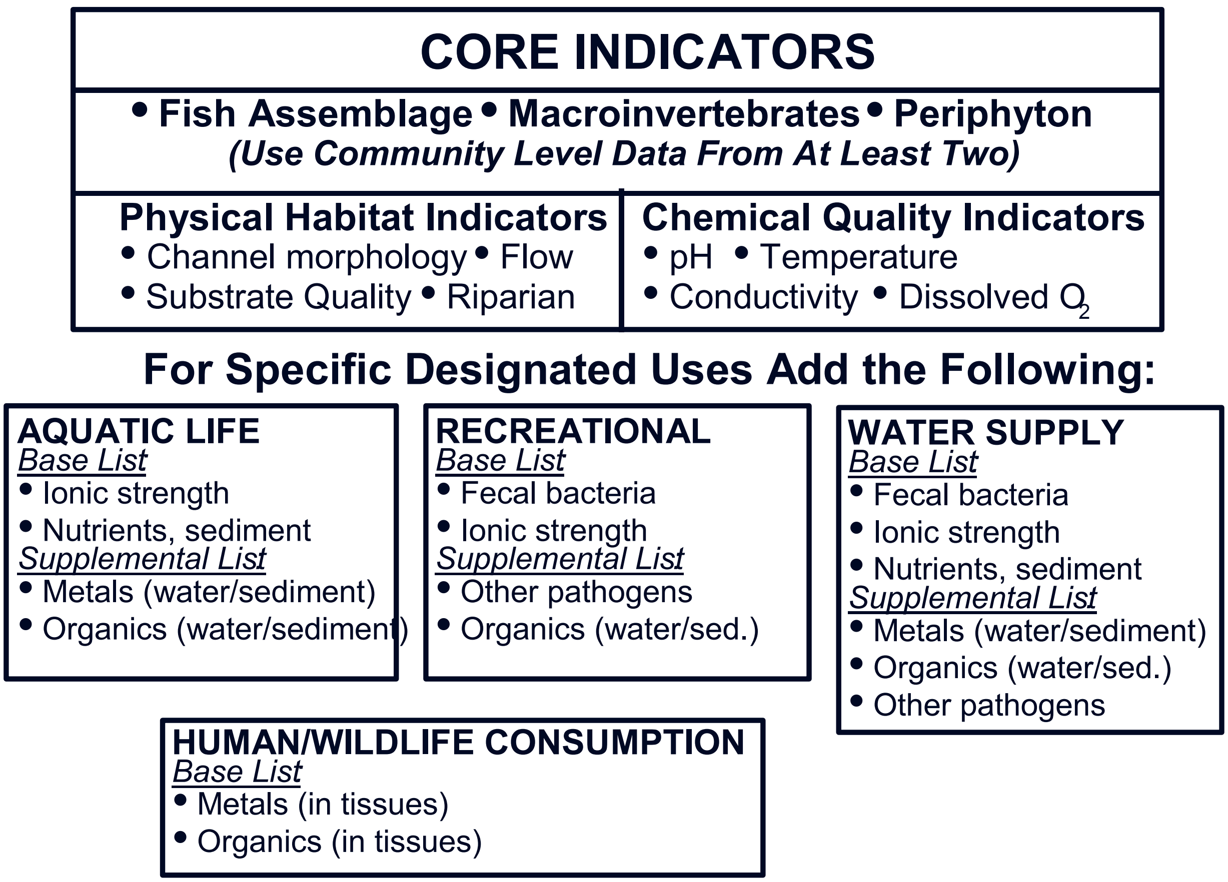


Figure 5. Core indicators and parameters by designated use to support an adequate watershed monitoring and assessment approach (after ITFM 1992 and Yoder 1998).

attributes. They are also measured directly in the field, thus providing rapid feedback to qualified analysts. Conventional approaches to monitoring and assessment attempt to formulate the assessment questions prior to deciding what to measure. However, adequate monitoring generates data and information about the core parameters in order to determine what the assessment questions should be, some of which cannot be sufficiently formulated without such data and information. Furthermore, they directly represent the fundamental attributes of aquatic ecosystems and, as such, comprise the baseline of adequate information needs for fundamental and recurrent assessment questions such as use attainment status, water quality standards compliance, use attainability analyses, delineation of associated causes/sources of threat and impairment, and basic reporting (305b report) and listing (303d listings). The **supplemental** parameters are added as the assessment needs (or questions) increase in diversity, quantity, and complexity of the setting. For example, a comparatively simple setting with one or two principal stressors may be adequately addressed by the core parameters plus the base list for aquatic life and recreation. As the complexity of a study area increases in terms of stressors and uses, the list will increase to include more of the supplemental parameters, the frequency of their collection and analysis, and the spatial intensity of the sampling design. This is a reasoned and stepwise selection of additional measurements, most of which require laboratory analysis. It can also include media in addition to the water column such as bottom sediments and organism tissues. All of this is dealt with in the initial planning of the watershed assessment and the development of a detailed plan of sampling.

Another dimension of cost-effectiveness is the capture of all relevant management objectives with the chosen suites of indicators. Table 1 relates indicator categories to classes of common water resource management program objectives. These may be addressed as part of the field sampling or accessed later in the analysis and reporting phases of the assessment process. These are critical components of the sequential analysis of the monitoring data and information, which relates designated use impairments to associated causes and sources. This approach also economizes sampling resources by scaling the intensity and complexity of the monitoring and assessment effort in accordance with the management issues to be addressed. This type of approach also allows for more flexible management responses that are attenuated by the information revealed about the environmental complexity of the setting, the quality of the aquatic resource, and the potential pollution problems encountered. Effective implementation of this process is improved through the experience and knowledge gained by conducting monitoring and assessment for many years and over a wide geographical area.

Indicator Discipline – Adherence to Indicator Roles

An important factor in achieving the cost effective approach just described is using chemical, physical, and biological indicators in their most appropriate roles as stressor, exposure, or response indictors. The accurate portrayal of the condition of aquatic resources depends on wider development and use of response indicators and adequate spatial monitoring designs conducted at the same scale of water quality management. Part of the solution to these challenges is to use indicators within their most appropriate roles. The EPA environmental Monitoring and Assessment Program (EMAP; U.S. EPA 1991) classified indicators as stressor, exposure, and response. Yoder and Rankin (1998) further organized the concept defining the most appropriate roles of parameters and measures when used in an adequate monitoring and assessment program.

Stressor indicators generally include activities and phenomena that impact, but which may or may not degrade or appreciably alter key environmental processes and attributes. These include point

*Table 1. Summary matrix of recommended environmental indicators for meeting management objectives for status and trends of surface waters (a boldface "**X" indicates** a recommended primary indicator after ITFM 1995; other recommended indicators are designated by a "√"). The corresponding EPA indicator hierarchy level (see Figure 6) is also listed for each suite of indicator groups.*

	Categories of Management Objectives					
	Human Health			Ecological Health	Economic Concerns	
Indicator Group	Consumption of fish/ shellfish	Public Water Supply	Recreation (swimming, fishing, boating)	Aquatic/ Semi-aquatic Life	Energy/ Transportation	Agriculture/ Forestry/ Mining
	Biological Response Indicators (Level 6)					
Macroinvertebrates		X	X	**X**		**X**
Fish	**X**	X	X	**X**		**X**
Semi-aquatic animals	X		X	**X**		X
Pathogens	X	**X**	**X**			X
Phytoplankton	X	X	X	X	X	
Periphyton				X		
Aquatic Plants		X	X	X	X	X
Zooplankton		X	X	X		X
	Chemical Exposure Indicators (Levels 4&5)					
Water chemistry	**X**	**X**	**X**	**X**	**X**	**X**
Odor/Taste	X	X	X			X
Sediment Chemistry	**X**	X	X	**X**	**X**	**X**
Tissue Chemistry	**X**	**X**		X	X	
Biochemical Markers	√	√	√	√		
	Physical Habitat/Hydrological Indicators (Levels 3&4)					
Hydrological Measures	X	X	X	**X**	**X**	**X**
Temperature	X	X	X	X	X	**X**
Geomorphology	X	X	**X**	**X**	**X**	**X**
Riparian/Shoreline	X	X		X	X	X
Habitat Quality			√	√	√	√
	Watershed Scale Stressor Indicators (Levels 3,4,&5)					
Land Use Patterns	X	X	X	X	X	X
Human Alterations	X	X	**X**	**X**	X	
Watershed Imperviousness (% of watershed)			√	√		√
	Pollutant Loadings Indicators (Level 3)					
Point Source Loads	√	√	√	√		√
Nonpoint Loadings	√	√	√	√	√	√
Spills/Other Releases	√	√	√	√	√	√

and nonpoint source pollutant loadings, land use changes, and other broad-scale influences that most commonly result from anthropogenic activities. Stressor indicators provide the most direct measure of the activities that water quality management attempts to regulate. **Exposure** indicators include chemical-specific, whole effluent toxicity, tissue residues, and biomarkers, each of which suggest or provide evidence of biological exposure to stressor agents. Fecal bacteria also serve as exposure indicators and are used as surrogates for response where direct human response indicators are either lacking or their use would pose an unacceptable risk. These indicators are based on specific measurements that are taken either in the ambient environment or in discharges and effluents, either point or nonpoint source in origin are measures and parameters that reveal the level or degree of an exposure to a potentially deleterious substance or effect that was produced by a stressor event or activity. Chemical water quality parameters and the concentrations at which they occur in the water column fulfill this role. Water quality criteria for toxic substances are developed to indicate chronic, acute, and lethal exposures. Exceedences of these thresholds, either predicted or measured, provide design targets for planning and permitting and assessment thresholds for monitoring and assessment. Fecal bacteria fulfill this role as well, indicating the level of risk posed to humans and other animals by exposure to various levels and durations of potentially harmful pathogens. **Response** indicators are measures that most directly relate to an endpoint of concern, i.e., ecological and human health. They are most commonly biological indicators, e.g., aquatic assemblage measures for aquatic life uses and human health for recreational uses and are the most direct measures of the status of designated uses. For aquatic life uses the assemblage and population response parameters that are represented by the biological indices that comprise biological criteria are examples of response indicators. For other designated uses such as recreation and drinking water, symptoms of deleterious effects exhibited by humans would serve as a response indicator, albeit these might prove more difficult to develop and manage. Response indicators represent the synthesis of stress and exposure (re: Figure 4) and are commonly used to represent overall condition or status. The key to implementing a successful indicators and watershed approach that serves as a basis for developing a synthesized report card is to ensure that indicators are used within the roles that are the most appropriate for each. The inappropriate substitution of stressor and exposure indicators in the absence of response indicators is at the root of the national problem of widely divergent 305(b) and 303(d) statistics reported between the states (NRC 2001).

Historically, states have used surrogate approaches to measuring and determining the status of designates uses. For aquatic life uses, chemical criteria have been cast in that role. For recreational uses, fecal bacteria continue to fulfill that role. Yoder and Rankin (1998) define the former practice as an inappropriate substitution of stress or exposure indicators for response. Comparisons of biological and chemical assessments show that the latter leads to listing of water bodies as impaired when they are not (type I error) or not listing when they are impaired (type II error). Rankin and Yoder (1990) using data over a 10 year period in Ohio and the Oregon Department of Environmental Quality (D. Drake, personal communication) using data from the 1990s, both showed that type II errors are the most prevalent, leaving up to 50% of the impairments detected by biological assessments undetected and undiagnosed. In the case of recreational uses, the reality of fecal bacteria exceedences and human health risks needs to be better reconciled.

A process for assembling information from cost-effective indicators comprised of biological, chemical, and physical measures used in their most appropriate roles can ensure that pollution sources are judged objectively and on the basis of quantifiable environmental results. Such an approach simultaneously assures that indicators will be representative of the elements and processes of the five factors that determine water resource integrity (Figure 1; Karr et al. 1986). An indicators hierarchy developed by U.S. EPA (1995a,b) provides a sequential process within which indicators can be linked to support assessment and management responses (Figure 6). It offers a structured approach to assure that management programs are, if necessary, adjusted based on environmental feedback (see also Figure 2). A comprehensive ambient monitoring effort that includes indicators representative of key variables within the five factors which determine the integrity of the water resource is essential to successfully implementing a true environmental indicators approach. For this approach to be successful, ambient monitoring must take place at the same scale at which management actions are being applied.

This integrated framework relies on the hierarchical continuum of administrative and true environmental indicators. This framework was initially developed by U.S. EPA (1995a). The original framework included six "levels" of indicators as follows:

Level 1 - actions taken by regulatory agencies (*e.g.,* permitting, enforcement, grants);
Level 2 - responses by the regulated community (*e.g.,* construction of treatment works, pollution prevention);
Level 3 - changes in discharged quantities (*e.g.,* pollutant loadings);
Level 4 - changes in ambient conditions (*e.g.,* water quality, habitat);
Level 5 - changes in uptake and/or assimilation (*e.g.,* tissue contamination, biomarkers, assimilative capacity); and,
Level 6 - changes in health, ecology, or other effects (*e.g.,* ecological condition, pathogenicity).

In this process the results of administrative activities (levels 1 and 2) are followed by changes in pollutant loadings and ambient water quality (levels 3, 4, and 5), all of which leads to measurable environmental "results" (level 6). The process is multi-directional with the level 6 indicators providing overall feedback about the completeness and accuracy of the process through the preceding levels. While the U.S. EPA (1995a) hierarchy employs point source terms, it is adaptable to nonpoint sources and media other than surface waters. Superimposed on this hierarchy is the concept of stressor, exposure, and response indicators (Figure 6) similar to that developed by the U.S. EPA Environmental Monitoring and Assessment Program (EMAP; U.S. EPA 1991). Stressor indicators include activities that have the potential to degrade the aquatic environment such as pollutant discharges, land use changes, and habitat modifications (level 3). Exposure indicators are those which measure the apparent effects of stressors and include chemical water quality criteria, whole effluent toxicity tests, tissue residues, bacterial levels, and biomarkers, each of which provides evidence of biological exposure to a stressor or bioaccumulative agent (levels 4 and 5). Response indicators include composite measures of the cumulative effects of stress and exposure and include the more direct measures of biological community and population response that are represented here by the biological indices which comprise the Ohio EPA

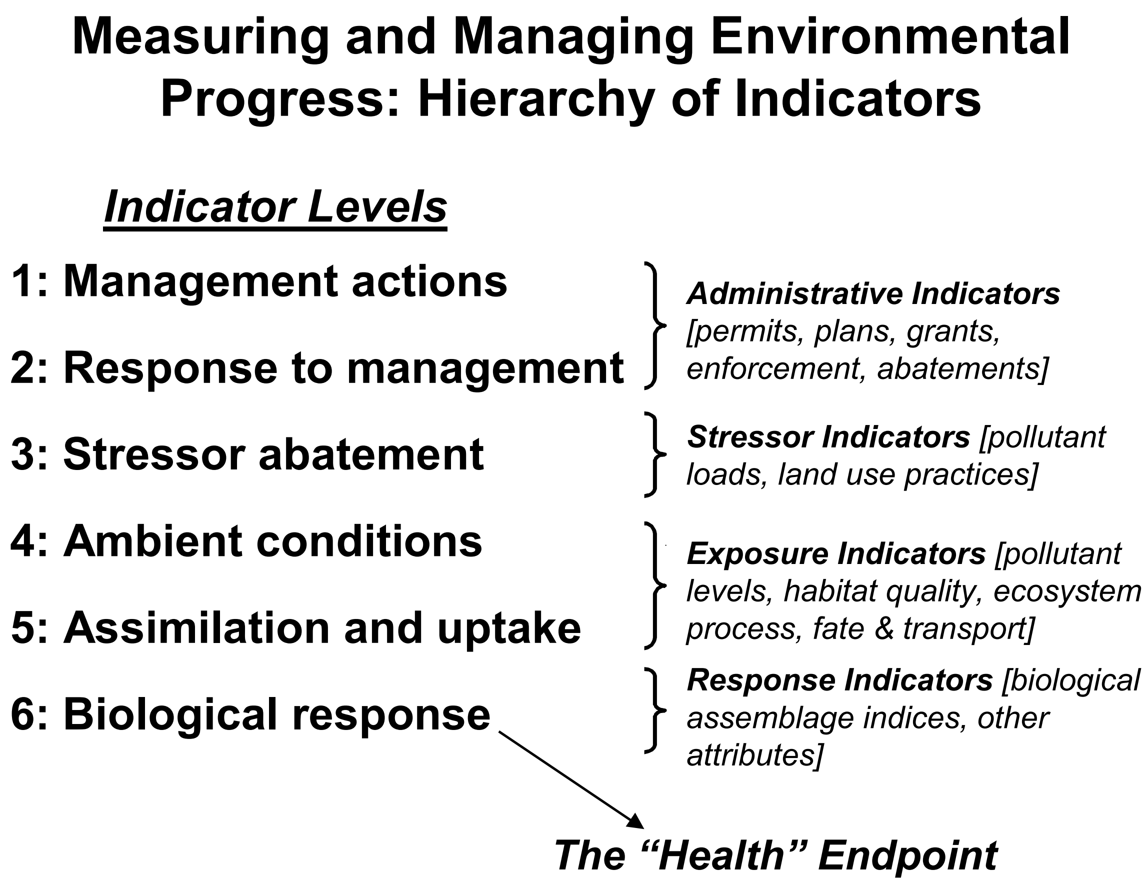


Figure 6. Hierarchy of indicators for determining the effectiveness of water quality management and maintaining appropriate relationships and feedback loops between different classes of indicators (modified from U.S. EPA 1995a).

biological criteria (level 6). Other response indicators could include target assemblages (*e.g.*, rare, threatened, endangered, special status, and declining species). All of these indicators represent the essential technical elements for watershed-based management approaches. The key is to use the different indicators within the roles that are most appropriate for each.

The processes for sequencing and synthesizing environmental data and indicators serves as a foundation for reporting on status and trends at all levels (national, regional, statewide, or local). The disciplinary process just described should minimize both type I and type II assessment errors. Such errors are a concern in the integrated 305b/303d reporting and listing process, in which both type I and II errors have been extensively propagated (Yoder and Rankin 1998; National Resource Council 2001). The results of these errors are waters that are not impaired are identified as needing corrective actions (type I error) or waters that are truly impaired are overlooked altogether (type II error). While this may be the most "visible" issue at present, the impact of such assessment errors can adversely affect other water quality management program areas. The process by which the basic data and information on which indicators are developed and used must be integrated at the outset, not as a "tack-on" at the end of the process. Bringing a more consistent and scientifically robust approach to indicators development and usage should lead to the correction of such errors and foster better policy and management outcomes as a result.

Key Indicators Are Tied to WQS - Designated Uses and Criteria

Water quality standards (WQS) establish the essential framework for developing measurable endpoints and criteria for deriving restoration and protection benchmarks. They consist of two parts – a designated use and criteria intended to protect and measure attainment of the designated use. They are used as targets for developing management strategies to achieve restoration and protection (e.g., wasteload allocations, TMDLs, BMPs, etc.) and for measuring the relative quality of water and aquatic ecosystems. Obviously, the more that WQS account for regional variability and characteristics inherent to the aquatic ecosystems of a region, the more relevant and accurate are assessments of quality and management strategies designed to achieve restoration and protection goals. WQS are an absolutely fundamental issue of adequate monitoring and assessment and the linkages between the two must be recognized (NRC 2001). States widely employ non-specific, general uses, which essentially represents a one-size-fits-all approach to designating and assessing surface waters. For example, states designate waters for the "protection and propagation of fish and aquatic life" of other general descriptions such as "cold water fishery". Such uses are not specific enough to foster the development of the more detailed criteria and indicators that are needed to address many of the deficiencies identified by the General Accounting Office (GAO 2000, 2003b) and NRC (2001). Furthermore, the use of direct biological measures and criteria is viewed as essential to making refined uses work. A few states (e.g., Maine, Ohio, Vermont) have developed refined use designation frameworks that are supported by numeric biological criteria and these have been extensively described elsewhere (Courtemanch 1995; Yoder and Rankin 1995a; Yoder 1995). This has given rise to the biological condition gradient framework, which has been under development and testing by U.S. EPA (Figure 7) in support of the development of a national process for tiered aquatic life uses.

Water quality criteria are largely expressed as chemical pollutant concentrations and sometimes as narrative descriptors. As such, they function as indirect surrogates for the endpoint described by a designated use. The designated use is a description of a desired state or set of attributes for a waterbody and the criterion is a measurable indicator that is a surrogate of use attainment. A criterion occupies a position at any point along the sequence of stress, exposure, and response (Figure 8). The NRC (2001) described this as the "position of the standard" and concluded that a criterion that is positioned closer to the designated use is a more accurate indicator of that use. In addition, the more precisely the designated use is stated, the more accurate the criterion will be as a result. Karr and Yoder (2004) modified the original figure to show its consistency with the previously described stress, exposure, and response roles of indicators. It provides a way to relate different types of criteria (chemical, physical, biological) and how to sequence each along a causal chain of events such as that portrayed by the hierarchy of indicators. Both the appropriate roles of indicators and the hierarchy for sequencing them along a causal chain of events are embedded in Figure 8. Including adequate representatives of each indicator role and their development and calibration in a state's WQS institutionalizes their usefulness to water quality management.

Data and Measurement Quality Objectives
Data (DQO) and measurement quality objectives (MQO) determine the level of detail and analysis that is required in support of an indicator or parameter. Frequently, these are defined by the state's WQS, either directly or implicitly and these comprise an important determinant of the

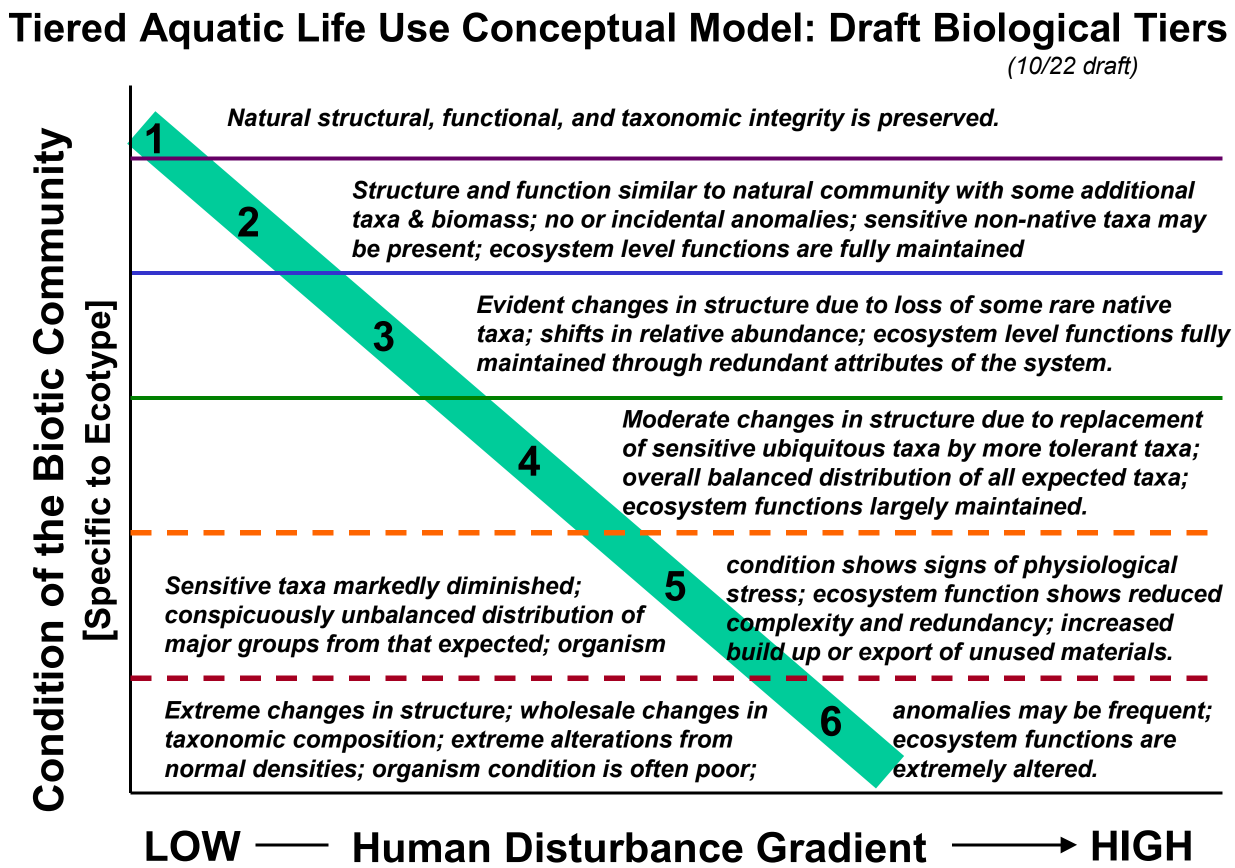


Figure 7. Refined aquatic life use conceptual model showing a biological condition axis and descriptive attributes of tiers along a gradient of quality and disturbance (U.S. EPA, Refined Aquatic Life Uses Working Group, 2001).

accuracy of assessments produced by a monitoring and assessment effort. For example, if a pollutant criterion is set at a concentration of 10 ug/l, then sampling and analytical methods that ensure detection to at least that concentration will be required. As such, the 10 ug/l criterion serves as the data and measurement quality objective. Furthermore, for many parameters it will be necessary to measure below the criterion threshold as there will be management issues of interest at lower levels. An example is defining reference condition for individual pollutants, which will require knowledge of the range of occurrence from minimum detection limit up to the criterion. For biological assessments, the issue includes how samples are obtained (effort, gear selectivity), how they are processed (subsampling, handling, preservation), how they are enumerated and identified (level of taxonomy), and the attributes that are recorded (species, numbers, biomass, anomalies). This illustrates both the qualitative and quantitative aspects of this issue. In biological assessment, taxonomic resolution is a key quality objective, as this not only determines the power of the assessment tool, but the diagnostic capabilities as well (Yoder and Rankin 1995b; Yoder and DeShon 2003). DQO/MQO can be governed by methods and protocol documents, but are much less ambiguous and debatable when they are codified in the state's WQS. Data and measurement

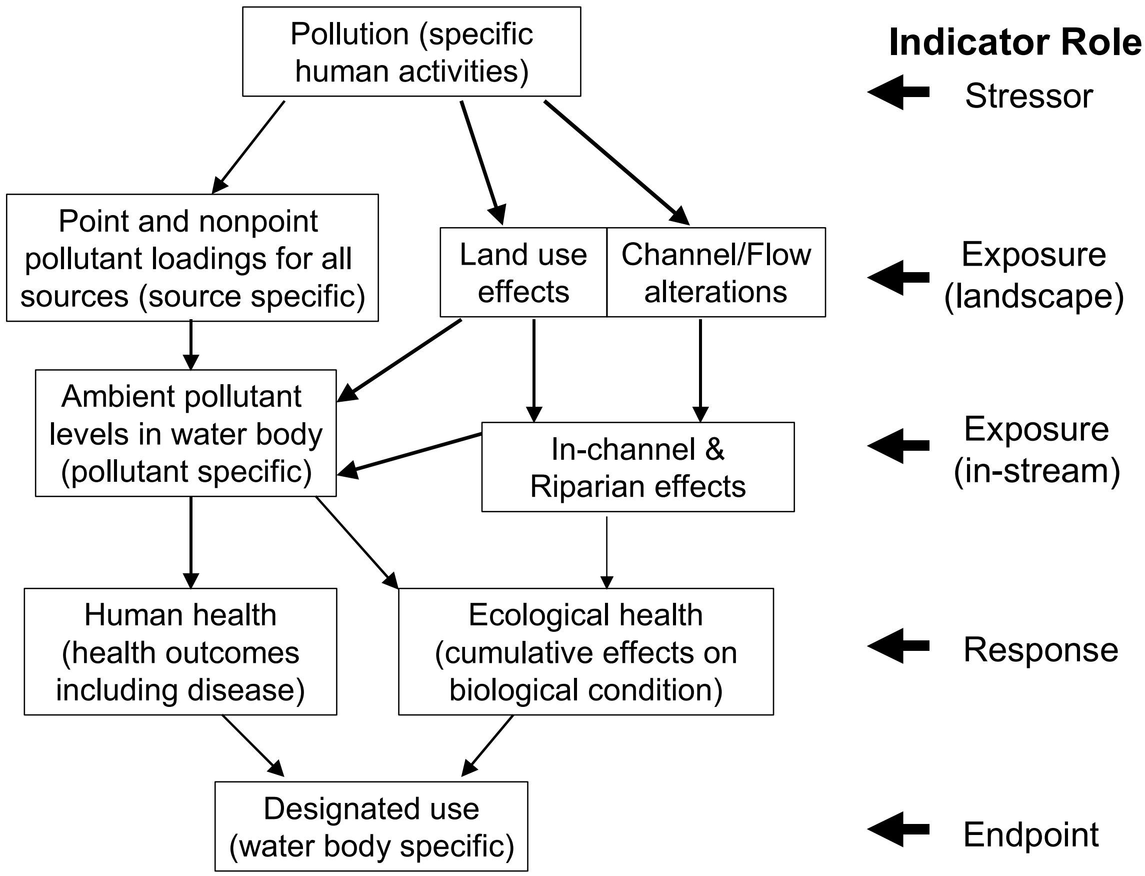


Figure 8. Position of the criterion (stressor, exposure, or response) illustrating the relationships between human activities, specific types of criteria, and designated uses that define the endpoint of interest to society (modified from NRC 2001). Their parallel roles as environmental indicators for each category is listed on the right. Arrows indicate directions and interrelationships along the causal sequence of stress, exposure, and response.

quality objectives inherently determine the overall capabilities of a monitoring and assessment program to accurately detect, quantify, and diagnose environmental status.

Strategic Issues

Adequate monitoring and assessment is an inherently strategic process. To fully realize the benefits of such requires an understanding of the multiple uses of the information in the management of water resources. A fundamental tenet of adequate monitoring and assessment is that the same set of core resources, methods, standards, data, and information should support multiple program management needs (Figure 9). It also requires a commitment to program maintenance and upkeep (i.e., maintenance of adequate resources, facilities, and professionalism) over the long term. Professionalism includes the qualifications of the monitoring and assessment personnel and their ability to carry out all tasks, including data analysis and the sequencing and interpretation of multiple indicators. Several of the indicators require specialized expertise in terms of data collection, field observations, laboratory methods, taxonomic practice, and data analysis and interpretation skills. Thus the professional qualifications of the personnel who execute and manage a statewide program is a pivotal issue.

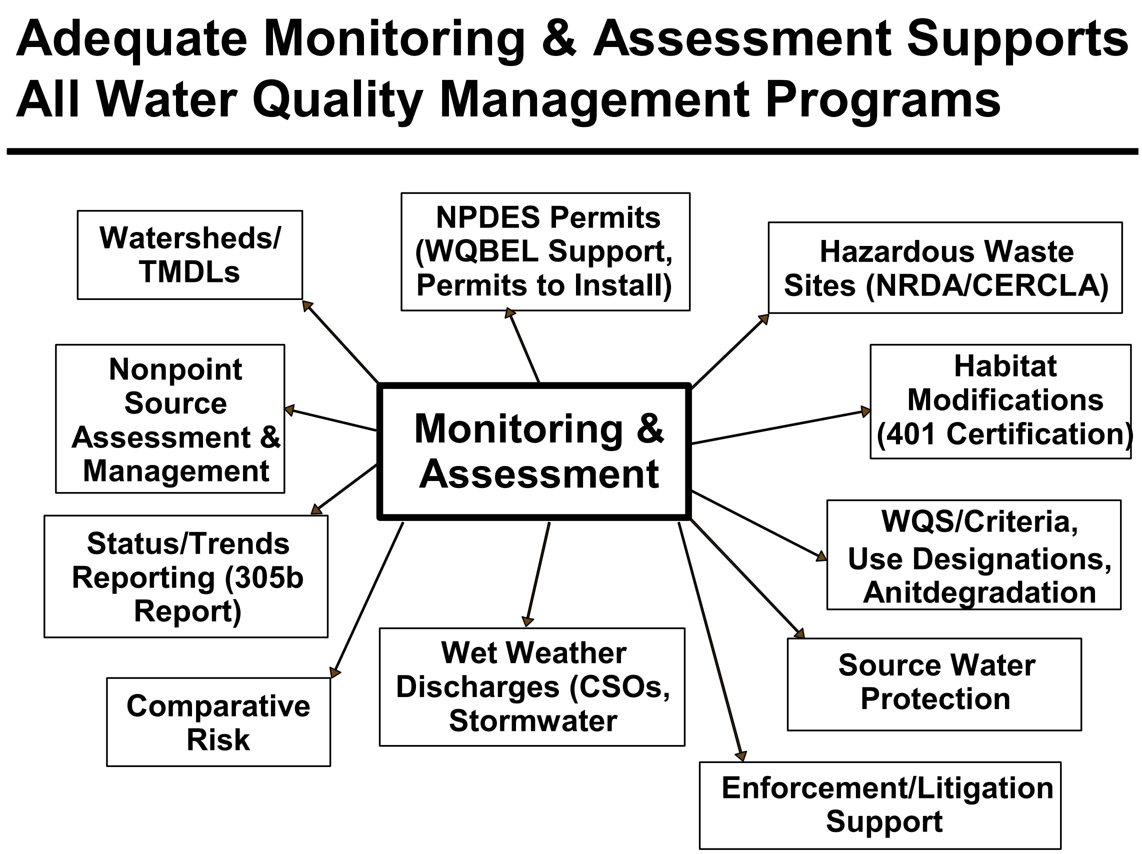


Figure 9. Adequate monitoring and assessment should be capable of supporting multiple program support needs with the same core base of indicators, parameters, and designs.

Two important functions of adequate monitoring and assessment include the functional support provided to individual management programs. The first includes tasks such as determinations of status at multiple scales, use attainability analyses, supporting the management of specific sources, and providing information to guide watershed planning and restoration processes (Figure 10; upper tier). The second is that of providing "strategic support" via the systematic accumulation of data, information, knowledge, and experience across various temporal and spatial scales (Figure 10; lower tier). This includes resources devoted to such tasks as sampling and maintenance of reference sites for determining regional reference condition and developing reference condition and benchmarks for key biological, physical, and chemical indicators and parameters. Many contemporary management needs are not well supported by conventional approaches to water

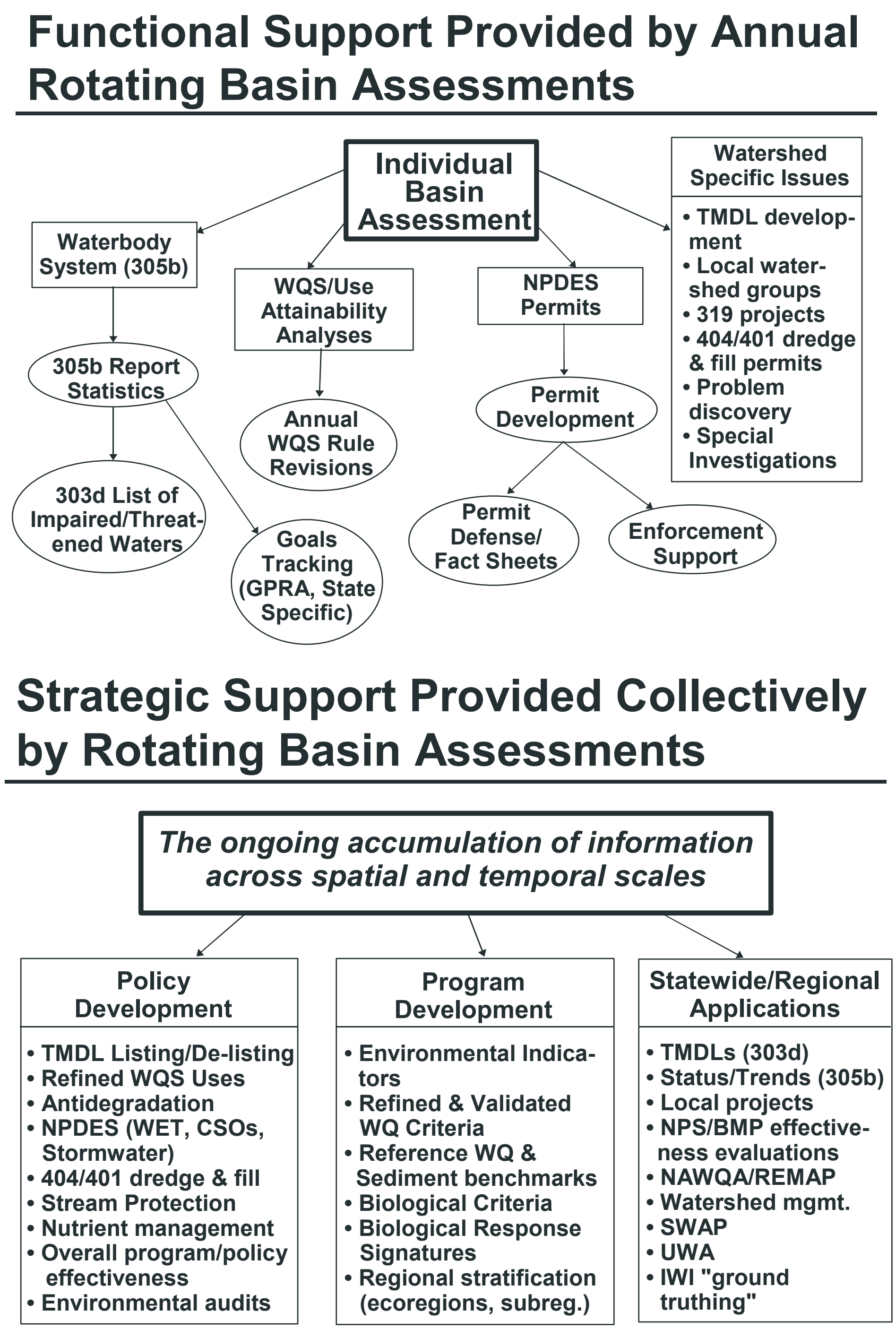


Figure 10. Examples of water quality management program support routinely provided by adequate monitoring and assessment at the watershed level (upper panel) and as a baseline support function delivered by routine monitoring over time (lower panel).

quality criteria and modeling, thus new ways of developing and applying benchmarks and criteria are needed. Developing criteria for nutrients and clean and contaminated sediments are examples. Other issues such as urbanization and habitat concerns will require landscape and riparian level indicators and objectives. All require robust spatial and temporal datasets. Coupled with this is the need to conduct ongoing applied research and exploratory data analysis with the monitoring program datasets, including the aggregate experience of the program. The ongoing accumulation of data, information, and assessment across different spatial scales provides both the datasets and the assessment experiences. This comprises the strategy for delivering the criteria and benchmarks that will not be delivered by the conventional approach to developing national water quality criteria.

Finally, the recognition that the most important product of adequate monitoring and assessment is the assessment, not just the data, is critical to achieving success. Data by itself has limited usefulness to environmental decision-making unless it is converted to useful information. This means having decision criteria and benchmarks fully integrated into the monitoring and assessment program. It also means adhering to the indicator sequencing and linkage processes that were previously described and most importantly, using indicators within their most appropriate roles. An integrated assessment should serve the needs of multiple programs by the same set of assessments, without the need to generate new or different datasets for each and every management issue.

MONITORING DESIGN OPTIONS

The design of monitoring and assessment incorporates the mosaic of chemical, physical, and biological indicators, their development, calibration, and measurement, and the spatial and temporal scales over which each is measured. In terms of how this has changed during the past four decades, Table 2 shows the important attributes and descriptors of these key elements that comprise an adequate approach to monitoring and assessment. The types of designs emphasized in the 1960s and 1970s include a primary reliance on fixed stations, upstream/downstream comparisons, a reliance on single control sites or paired watersheds, pass/fail assessments, and general designated uses that acted as goals for abatement programs. That approach is now being replaced by whole watershed assessments, performance expectations based on regional reference condition, stratified survey designs, proportional assessments, and tiered or refined uses that incorporate both regional and ecological realities and expectations. The latter approach is much more able to demonstrate results and phenomena at ecologically meaningful scales and which incorporate the broad spectrum of human disturbances. As such, this type of monitoring is not only better able to produce more refined goals and criteria, but foster a better integration of important chemical, physical, and biological factors into decision and policy-making.

Table 2. Comparison of key attributes and characteristics of monitoring and assessment issues and trends in indicator development and use, condition assessment, and spatial design over the past four decades.

Attribute/Characteristic	"Old" Technology	"New" Technology
Spatial Design	Fixed stations, paired watersheds	Whole watersheds (11-14 digit HUC scale)
Assessment Design	Upstream/downstream, Single control sites; Pass/fail	Regional Reference Sites/Condition; Proportional assessments
Primary Indicators	Chemical parameters "Pollutant focused"	Biological Criteria "Resource focused"
Assessment Criteria	General goals	Refined/Tiered goals
Integration	Little or none	Multiple indicators, Sequential process
Data/Design Standards	Few or none Low/no standardization	Well defined, systematic, standardized

The “new” technology emphasizes a reliance on integrated assessments casting chemical, physical, and biological indicators in their most appropriate roles as stressor, exposure, or response indicators. It also is governed by standards of data and design quality where the demands of decision-making and the need for accuracy in the resulting assessments are supported by producing data of a sufficient quality so as to minimize assessment errors.

An important and fundamental premise of adequate monitoring and assessment is that it be conducted at the same spatial scale at which management is being applied. This simple premise allows management policies, approaches, and activities to be linked more closely to their environmental consequences as revealed by monitoring and assessment. For example, management of point sources includes concerns for impacts to the immediate receiving waters, the severity and extent of any extended impacts, and the collective impacts of multiple and overlapping sources. In the immediate receiving waters, a common concern is acute toxicity in the mixing zone that results in lethality or avoidance. Thus sampling in the receiving waters should not only include the appropriate mix of indicators, but sampling targeted to the mixing zone itself. The determination of impacts beyond the mixing zone is determined by sampling at intervals downstream so as to allow the measurement of the severity and extent of any adverse impacts, i.e., how extensive are departures from indicator goals or thresholds and how far do these extend downstream? The collective impact of different types of point sources can then be accomplished by aggregating these types of data over larger regional and even statewide scales, serving the need to determine if there are patterns and phenomena associated with specific types of sources. In this case example, an intensive survey design served as the spatial design.

Several spatial designs are available to support the multiple needs of water quality management programs. The key is to develop and use a design that satisfies *all* program needs in the most cost-effective manner. Cost-effectiveness in this case means paying attention to the timeliness needs of the program in addition to the spatial comprehensiveness of the monitoring and assessment. Five general sampling designs are described and include examples in which they have been applied for biological assessment, as follows:

Option 1 – Fixed station design;
Option 2 – “Synoptic” design;
Option 3 – Intensive survey;
Option 4 – Geometric design; or
Option 5 – Probabilistic design.

In the following discussion of the attributes, advantages, and disadvantages of each design, the focus is on lotic surface waters and the watershed. While some of these designs have been used to support lake and reservoir, wetland, and estuarine monitoring programs, the emphasis has been on watershed units, specifically rivers and streams. It has been suggested that all waterbody types within a watershed unit should be addressed and would seem workable for lakes/reservoirs and wetlands. This would foster a more integrated and complete assessment of each watershed unit. A different approach for larger water bodies may well be needed, but obvious linkages should be made to watershed based efforts whenever possible. Given these diverse needs and issues, it is certain that more than one design will be needed to support a comprehensive and adequate monitoring and assessment program, a fact recognized by EPA's CALM guidance (U.S. EPA 2003).

Option 1 – Fixed Station Sampling Design

Fixed station monitoring networks have been employed by state and federal agencies for decades, some dating back for more than 60 years. The most notable of these networks are the National Ambient Water Quality Monitoring Network (NAWQMN), principally operated by the states in compliance with the program requirements of U.S. EPA under the Clean Water Act (CWA). The U.S. Geological Survey operates the National Stream Quality Accounting Network (NASQAN) which serves much the same function and purpose of NAWQMN and coincides with USGS flow gauging stations. Other fixed station networks exist and include state monthly and quarterly water quality stations, Great Lakes tributary stations, and a few select programs operated by industries and municipalities. What all of these networks have in common is that the stations are established at reasonable access points where water samples can be quickly obtained and fixed sampling equipment can be established. They are sampled at regular intervals (monthly, quarterly, or with continuous monitoring equipment) and their spatial density is comparatively sparse. In addition, the measures are predominately chemical/physical with a prescribed list of parameters to be analyzed. For example, most monthly sites are sampled for basic field parameters such as temperature, dissolved oxygen (D.O.), pH, and conductivity, and a suite of conventional and demand parameters such as BOD, suspended solids, primary nutrients, and ionic strength parameters. Toxicants such as heavy metals and pesticides are sampled either less frequently (i.e., quarterly) or at specific sites where these pollutants are an issue of concern.

In the early 1970s, EPA initiated a pilot biological program in which biological samples were collected from a subset of the NAWOMN stations. This program included macroinvertebrates and periphyton, with some states adding fish tissue analyses. The goal of this program was to provide real world water quality data to determine status and trends in relation to the water pollution control programs of the day. The monthly sampling design was implemented to account for seasonal variations both natural and human induced. The quarterly sampling of toxic parameters was the result of cost limitations. Biological sampling was added later as the interest in biological assessment was just beginning. In real operational terms, this program fell short in delivering the type or quantity of information that was needed to not only determine status and trends, but to support day-to-day water quality management. In many states, fixed station networks have been reduced in terms of the number of locations sampled, but they have not been completely abandoned. Many states have maintained a skeletal network primarily for the purpose of maintaining the long period of record and because of a continuing program requirement by U.S. EPA. An example of an ongoing network in Indiana appears in Figure 11.

In terms of status and trends and how this relates to determining water quality management program effectiveness, there are some good examples of the value of fixed station data. Figure 12 shows results for chlorides and pH from a long term chemical monitoring station in the Salamonie River (Indiana) and the results of a seasonal Kendall test for any trends. IDEM performed

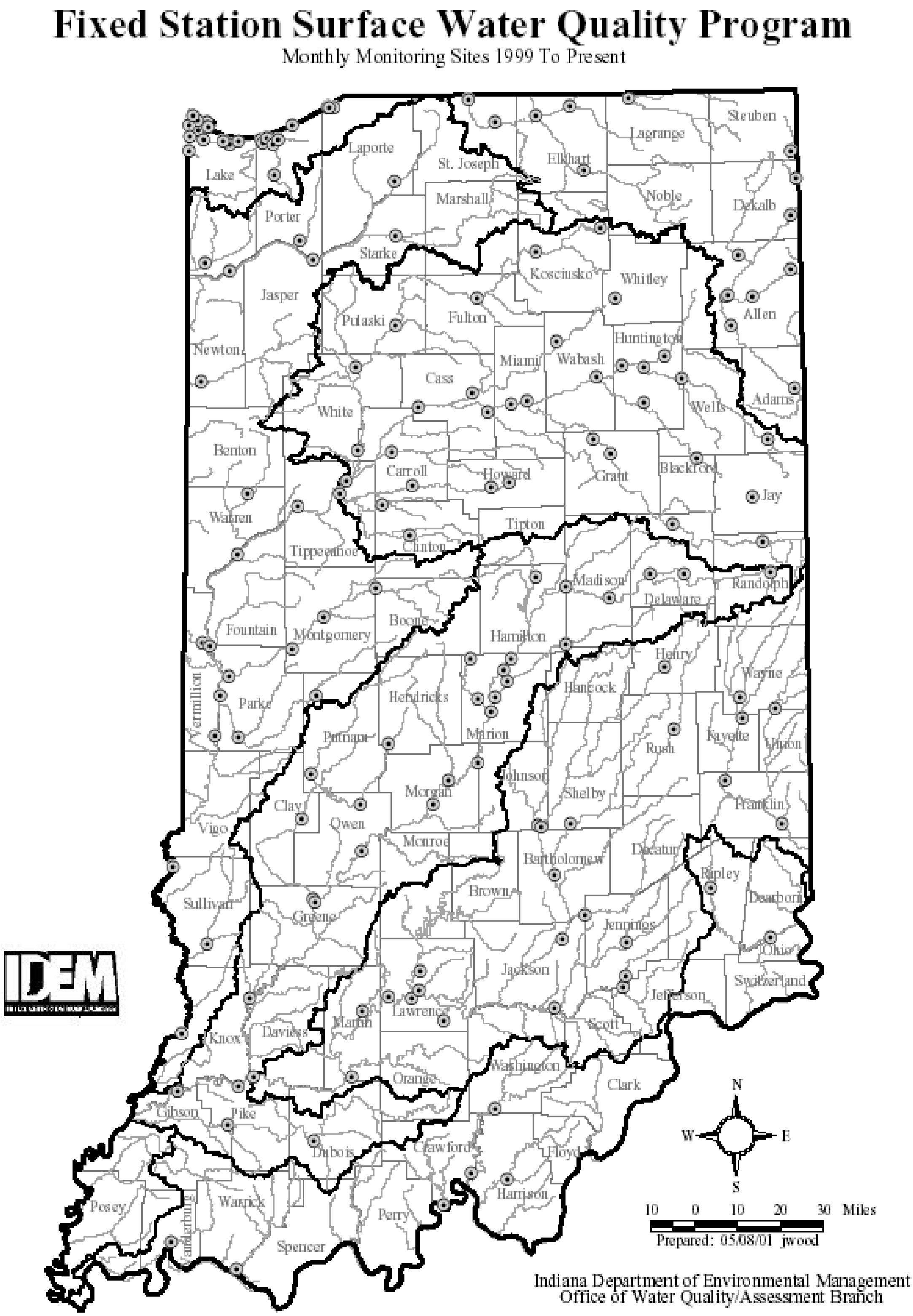
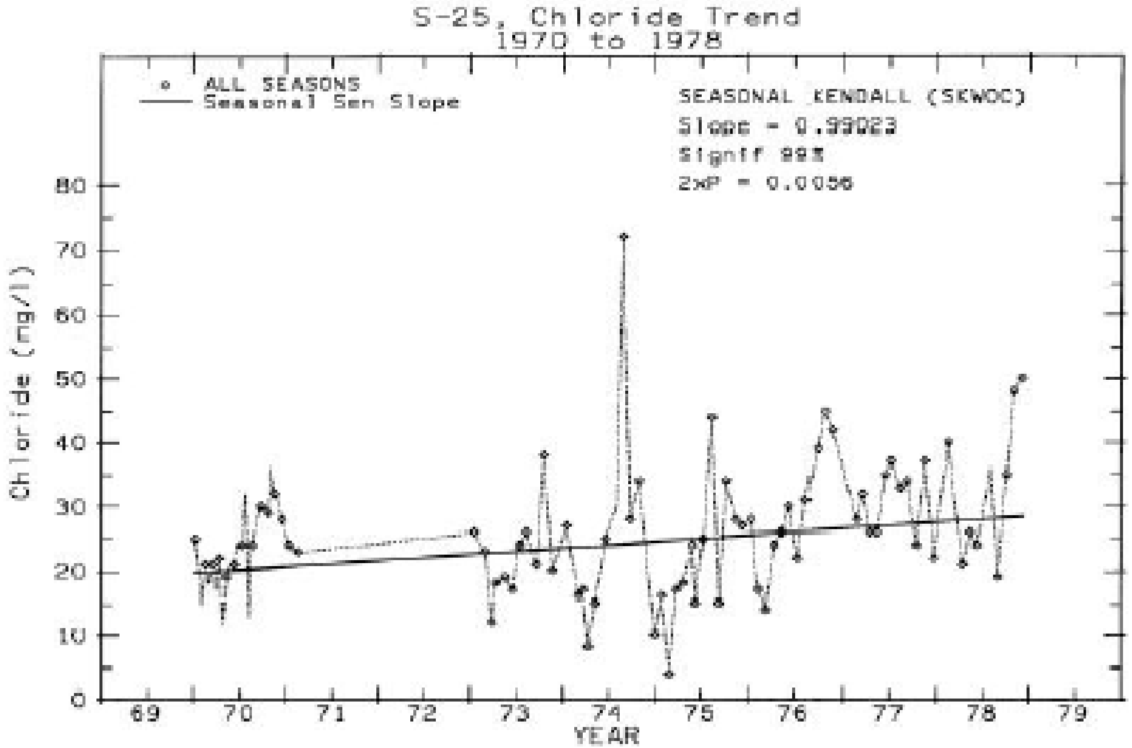


Figure 11. An extensive network of fixed station monitoring sites operated by the Indiana DEM.



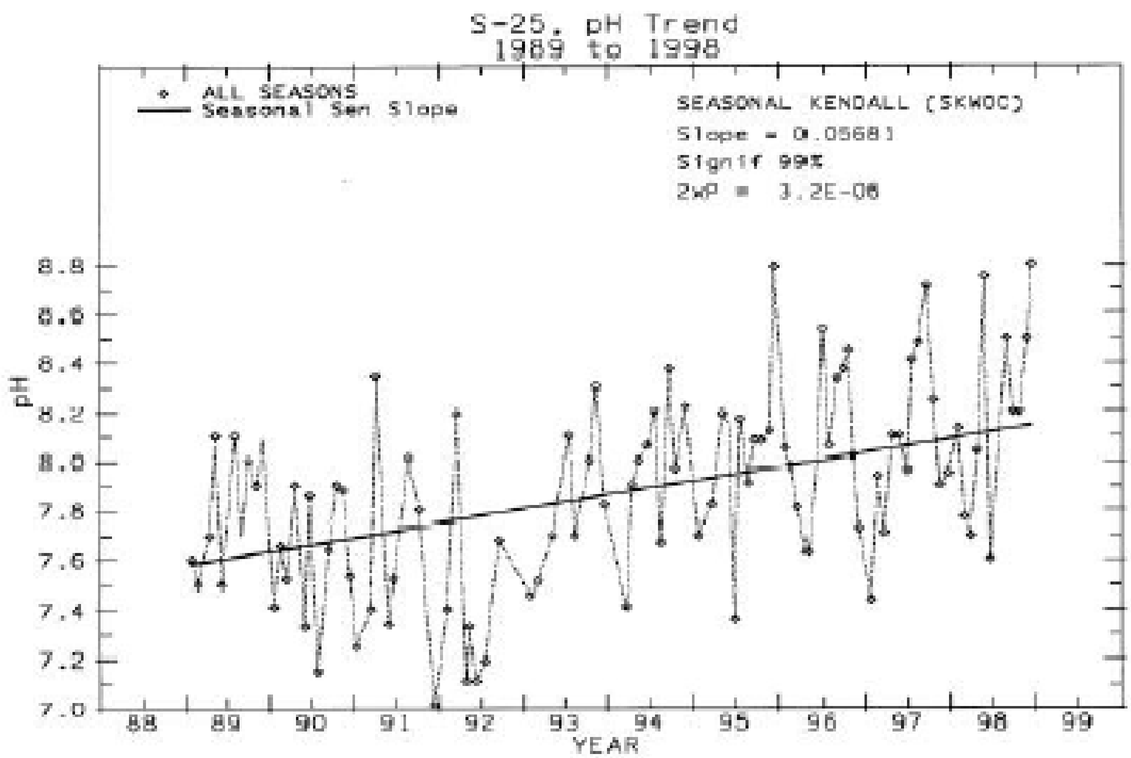


Figure 12. Example of fixed station data analysis showing results of a seasonal Kendall test of chlorides (1970-1978) and pH(1989-1998) trends in the Salamonie River at Lancaster.

approximately 1500 of these tests on their fixed station database (IDEM 1998) and they are used to assess trends in key parameters and spur management action when necessary. Their value thus far has been to demonstrate improvements in formerly grossly polluted waterbodies, but they fulfill an important baseline need of water quality management by maintaining awareness of changes in baseline variables through time.

Biological data can also be used to portray similar changes through time and completes the stress-exposure-response sequence. Figure 13 shows the changes over a nearly 25-year period in the lower Cuyahoga River downstream from Akron, Ohio for the fish and macroinvertebrate assemblages as represented by the Ohio IBI and ICI (Ohio EPA 1987). Again, the improvements documented in a grossly polluted water body at a fixed location some 18 miles downstream from the Akron municipal wastewater treatment facility corresponded to reductions in loadings of ammonia-N, BOD, and the later abatement of acute and chronic toxicity, in the effluent. Biological data used in this manner yields the advantage of synthesizing the cumulative effects of multiple stressors and pollutants through time. However, the fixed station being located 18 miles downstream from the discharge leaves the condition of the river in that distance unanswered.

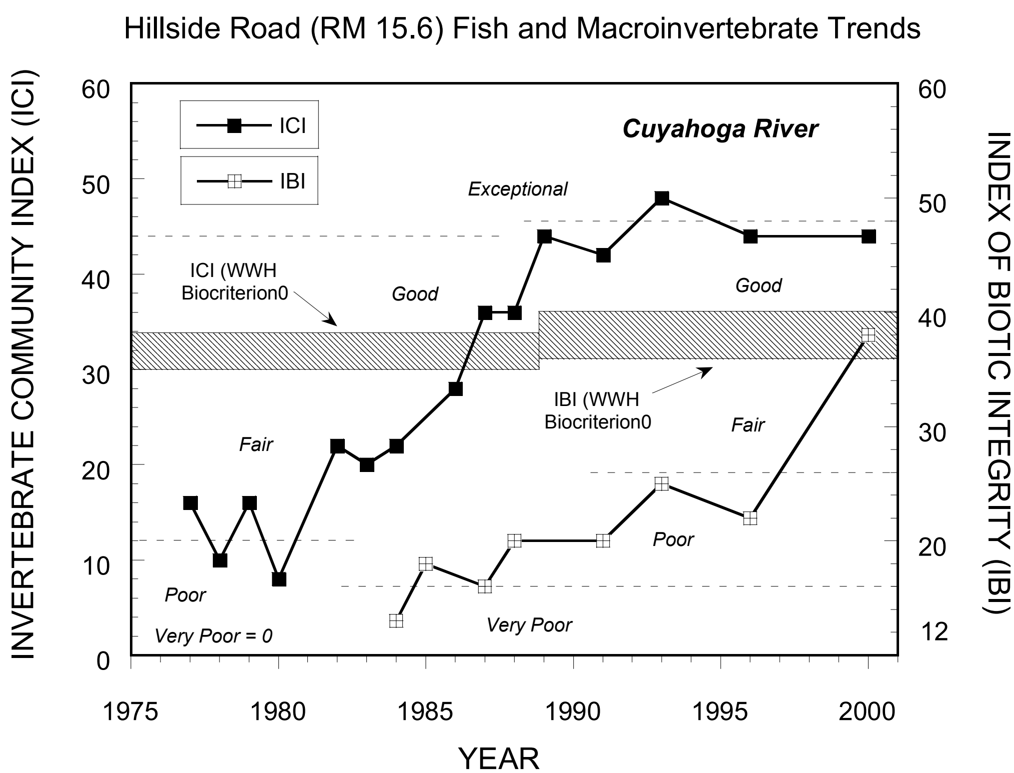


Figure 13. Temporal changes exhibited by the fish and macroinvertebrate assemblages at a single location in the Cuyahoga River, 1977-2000, in terms of the IBI and ICI.

The preceding examples illustrate a principal strength of the fixed station design - the production of long-term datasets. Once such networks are established they represent a unique resource in terms of the period of record and there is an understandable desire to continue sampling such sites. A fixed station sampling network also simplifies site selection and streamlines the process of sampling as site locations become familiar over time. A depth of understanding may also develop for these sites regarding the relationships between biological processes, natural variability, and human activities. Major weaknesses associated with this approach, when used alone, include a lack of spatial continuity, fixed distances from specific sources of pollution and other forms of degradation, and a comparative inability to extrapolate the results at a single site to unsampled areas. Sites are often selected for ease of access, proximity to road crossings, or proximity to a gauging station. Selection on the basis of convenience can lead to biased results, that is, assessments that are relevant only to the sites sampled, and not representative of watershed or regional conditions.

Option 2 –"Synoptic" Sampling Design

States are required by EPA to report the condition of their waters in terms of the proportion of stream and river miles, lake acres, etc. attaining or failing to attain their designated uses. EPA also strongly encourages states to assess 100% of all water bodies within a five-year time frame. To meet both of these objectives, some states have opted for a spatial design that is often referred to as "synoptic." Synoptic is not a strict statistical term, but rather is a descriptive one suggesting a broad view of the whole or an overview. This approach differs from a fixed station approach in that sites are sampled periodically (i.e., once every five years). It can be applied within discrete watershed areas such as major river basins or it can be applied to an entire jurisdictional region such as a state. In the latter, synoptic designs may include sampling in every watershed unit, which can result in a wide dispersal of a limited number of sites to cover the entire area in a fixed time frame (e.g., five years). The five-year basin approach (Figure 14) employed by many states is easily adapted within this design and it provides a way to allocate limited monitoring resources. The intent of some synoptic networks is a "snapshot" of water quality during the time of sampling and can be conducted on a river basin scale as opposed to statewide. The Indiana DEM provides one such example (Figure 15).

The goal of statewide efforts are usually to sample in every watershed with the design inherently assuming a census. When this design is used to assess statewide status, targeted monitoring sites are frequently allocated within large watershed units (e.g., 8 digit HUC[2]). Major river mainstems and their tributaries are frequently emphasized and sites are widely dispersed resulting in extensive extrapolation of the results. Locations for these sites may be positioned to reflect the accumulated impacts of upstream influences (i.e., located near the mouth of major drainages). This design is used to achieve statewide or region-wide coverage in a specified time frame (e.g., five years) with limited or fixed resources. The desire to achieve complete coverage in a fixed time period is primarily driven by previous EPA monitoring guidance, which espoused a goal of "100% coverage" of a state's waters within a five-year time frame. This was further driven by the inherent desire to

[2] HUC – hydrologic unit code; HUCs range in size from regional (21 units nationwide) to cataloguing (2150 units nationwide) and can be used to indicate an area contained within.

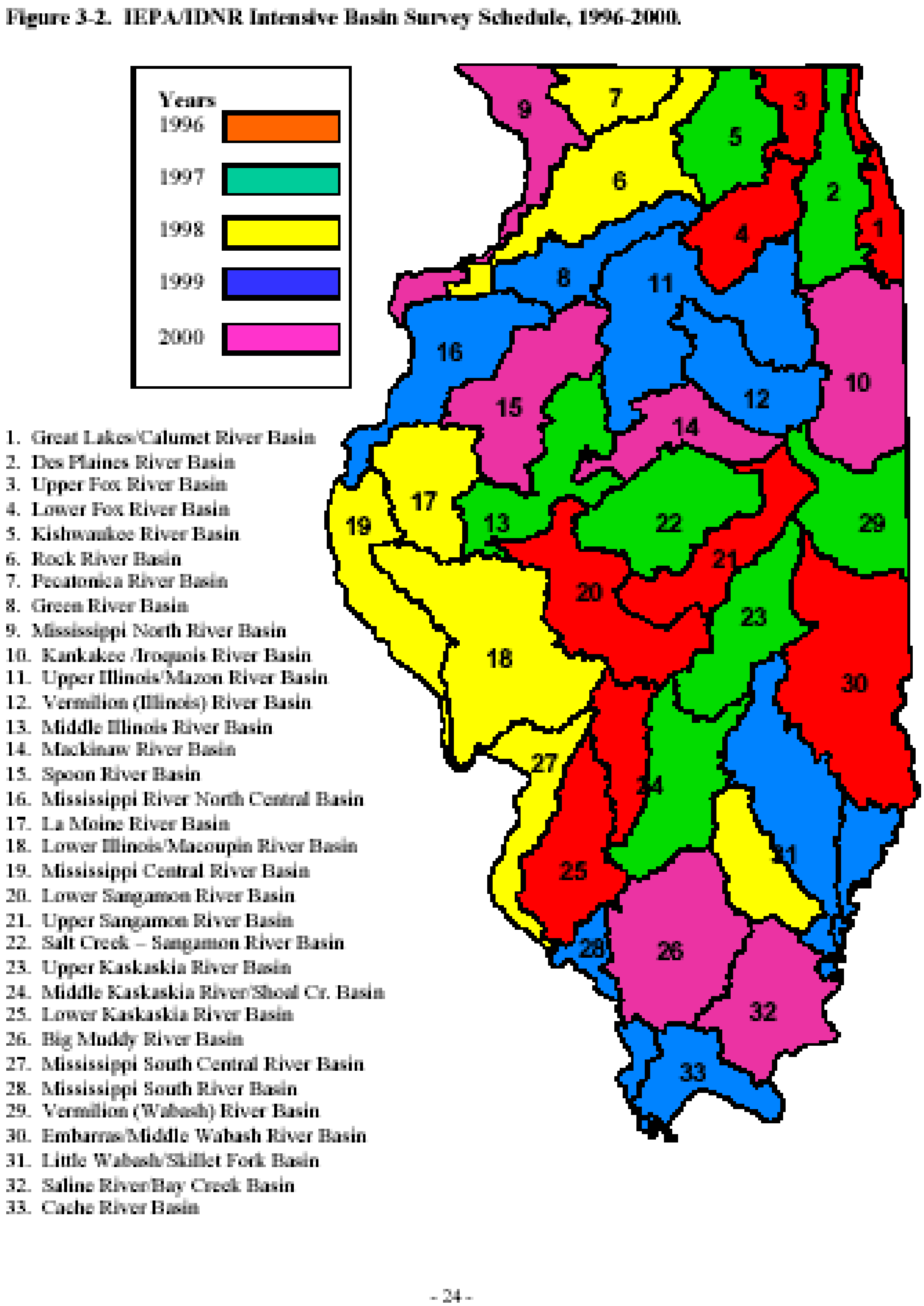


Figure 14. Rotating basin approach used by Illinois EPA. Monitoring is conducted in each subbasin rotating through the state in five years.

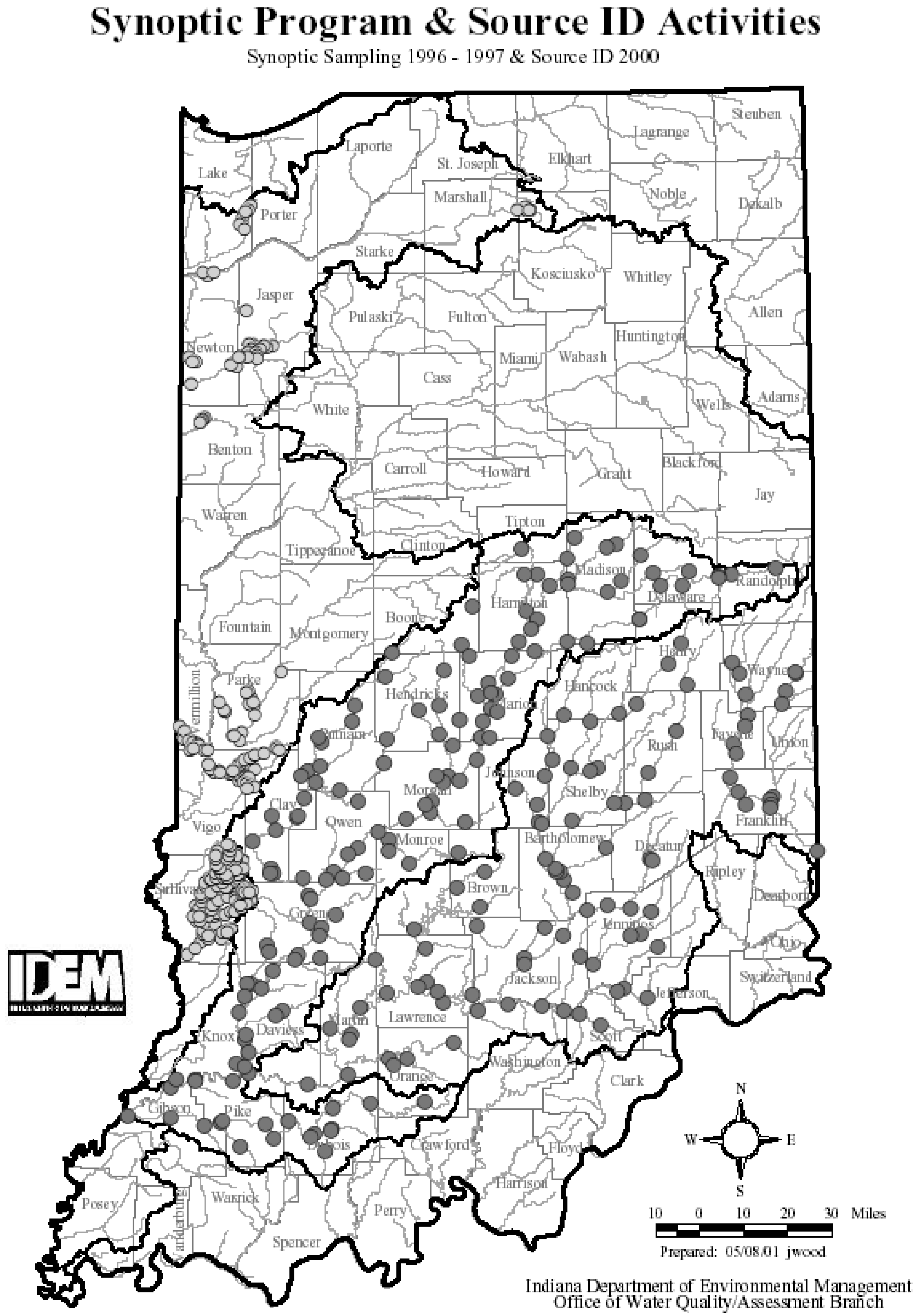


Figure 15. Synoptic and source identification sampling networks operated by Indiana DEM.

have an assessment of status for 100% of jurisdictional water bodies. Because of fixed resources, spatial intensity is functionally diluted to achieve statewide coverage. This often results in the need to further stratify the aquatic resource, i.e., sampling only wadeable streams. This approach also necessitates the extrapolation of sampling results at a single site to many miles of river and stream. For example, EPA guidance recommends extrapolating sampling results 10 miles in wadeable streams and 25 miles in non-wadeable rivers as a default criterion and in the absence of information to the contrary. This is done in order to accumulate assessed miles for the purpose of 305b reporting and is the purported strength of this design.

In regionally focused approaches like that employed by Indiana DEM (Figure 13), the goal is to provide screening data for determining if and what types of problems might exist in relation to different types of land use, stream sizes, confluences, etc. It is presumed here that the discovery of any problems would be followed up by more spatially intensive sampling given the multiple designs that are used by IDEM (IDEM 2001). The utility of this approach was demonstrated in the development of a fish assemblage assessment of the non-wadeable rivers of Wisconsin by Lyons et al. (2001), which employed a version of a synoptic design to all the large rivers of the state. The results were used to assess the relative contributions of major types of impacts and their comparative severity (Figure 16).

The weaknesses of this approach can be significant and mostly involves the non-random approach in sampling site selection. It results in a biased database, which can make aggregate estimates of status over large areas questionable. The extent of data extrapolation can be quite large and is a source of error in terms of representing aggregate resource condition and status. The design can also lack of site-specific relevance making direct program comparisons and assessments difficult and only generally relevant at best. Sampling sites located several miles downstream from a source of concern may or may not provide a relevant assessment of impact or about upstream reaches. Sites can be compared from one year to the next, but comparatively large changes may need to occur to be statistically significant.

Option 3 – Intensive Surveys

An intensive survey is defined here as spatially intensive sampling of localized stream or river segments or a distinct subwatershed area. The fundamental goal of this design is to comprehensively assess all possible sources of stress and influence within a localized river reach or discrete subwatershed area. It is critically dependent on the ability to identify and locate potential sources of human influence and natural variation prior to and during sampling. A comprehensive planning process is generally conducted for the purpose of developing a detailed plan of study, which then guides site selection. It is easily amenable to serving as the principal design of a rotating basin approach. The design is spatially intensive and requires multiple and closely spaced sampling sites within a defined reach of a stream, river, or subwatershed. This may include a few sites in a relatively simple setting (small wadeable stream, one or two sources) or tens of sites over many miles in larger rivers and complex watershed areas. An important objective is the longitudinal portrayal and interpretation of monitoring results in spatial relation to sources of potential change and stress. The early concepts of Bartsch (1948) and Doudoroff and Warren (1951), which demonstrated how the influence of pollution changes along the length of a flowing

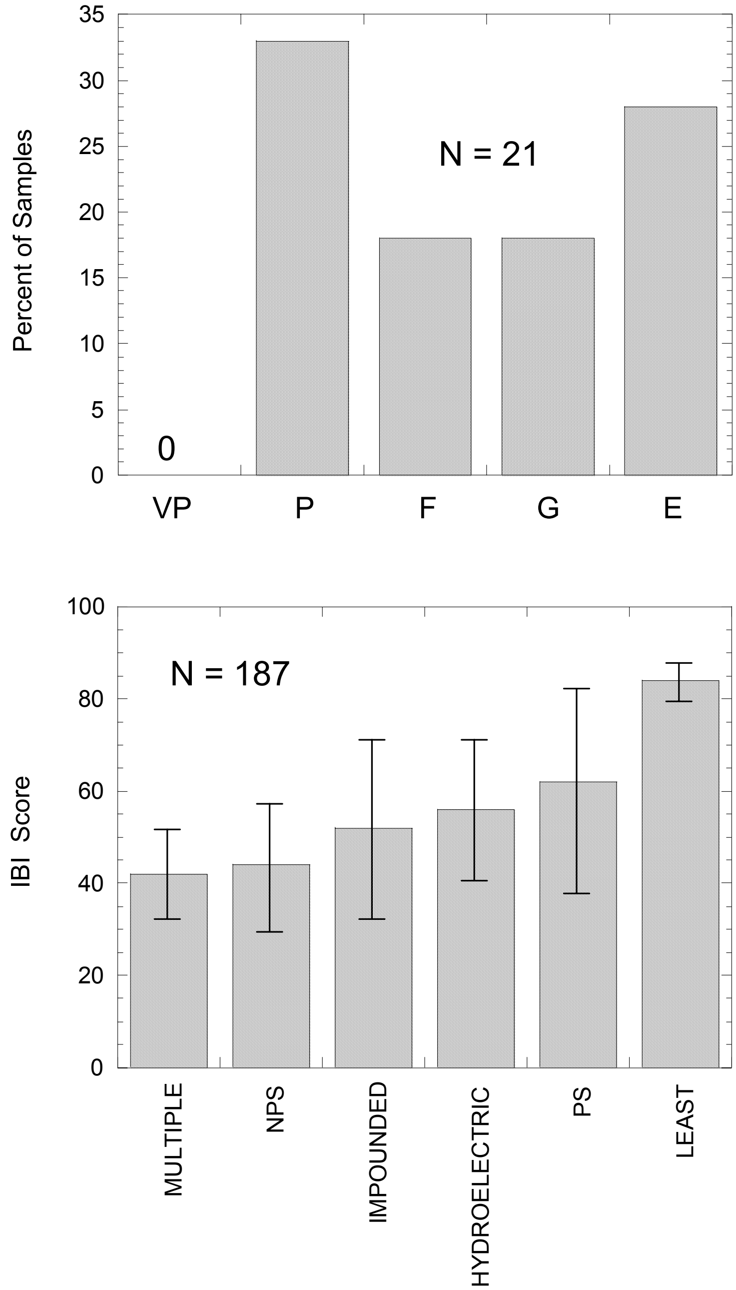


Figure 16. Mean IBI scores and 95% confidence intervals (lower panel) and the distribution of IBI scores among five condition ratings (upper panel; VP = very poor; P = poor; F = fair; G = good; E = excellent) for the hydroelectric impact type. Data is from 187 large river sampling sites in Wisconsin (after Lyons et al. 2001).

water body (i.e., pollution zones) likely gave rise to this type of monitoring design. This includes sampling in reaches that are upstream from the upstream most sources of potential impact, in areas of immediate impact and potentially acute effects, through zones of increasing and lessening degradation, and zones of eventual recovery.

This design is commonly used to support water quality management at the local, reach, and subwatershed scales. It also includes elements of "upstream/downstream" and paired watershed designs. Also inherent in this design is the goal of developing an understanding of how different parameters and indicators change in an upstream to downstream direction, in proximity to specific sources of stress and changes from immediate effects through the various stages of longitudinal recovery, and correspondence to changes in land use. This includes attempting to determine the role of specific sources as well as the accumulation of effects by multiple sources. This design must adequately define the condition of the water resource first and the influences of the sources based on the feedback from the indicators. For example, large mainstem rivers must frequently be treated as a single study unit in order to understand how changes take place along a longitudinal continuum with respect to both natural and anthropogenic influences. Important in the delineation of these study units are natural features and transitional boundaries (e.g., cold to warmwater, geologic phenomena), clusters of anthropogenic sources (e.g., major urban/industrial area, dams and impoundments, etc.), and transitions in land use. Some study areas may include up to 100-mile long river reaches in order to capture these types of influences and provide important geographic context for interpreting results at any given location. Ohio EPA has operated such a design for nearly 25 years (Figure 17).

An example of river specific results from this design shows the longitudinal results of the fish IBI in the Scioto River during three years over an 18-year time frame (Figure 18). Not only does this design yield a detailed assessment of status for a particular stream or river reach, it can also demonstrate changes through time. In addition, it illustrates the extent and severity of indicator responses along the longitudinal continuum. When this information is sequenced with stressor and exposure indicators using the hierarchy of indicators process described previously in figure 6, the results and effectiveness of water quality management programs through time clearly emerges. To continue the example from Columbus, Ohio the sequencing of monitoring results through the hierarchy of indicators illustrates the effects of water quality based permitting and financial assistance via the former construction grants program and current revolving loan programs. The intensive survey design in conjunction with a fixed station design demonstrate the effectiveness of water quality management in achieving not only chemical and biological improvements in the Scioto River, but restoration of the designated aquatic life use. The sequential positioning of the various chemical and biological indicators (Figure 19) follows the hierarchy of indicators process of U.S. EPA (1995a). This design is also amenable to using tools such as the Area of Degradation Value (ADV) and biological response signatures (Yoder and Rankin 1995b; Yoder and DeShon 2003) to further quantify resource response and trends through time (Figure 20). The ADV example quantifies the changes observed in the biological condition of the Scioto River and to demonstrate the biological impact and recovery before and after various technological changes made at the Columbus southerly WWTP. In this example, all of the data years can be viewed sequentially using an expression that communicates incremental severity and extent in addition to the bivariate impaired/unimpaired condition. Such tools allow water quality management programs to see their results in incremental rather than pass/fail terms.

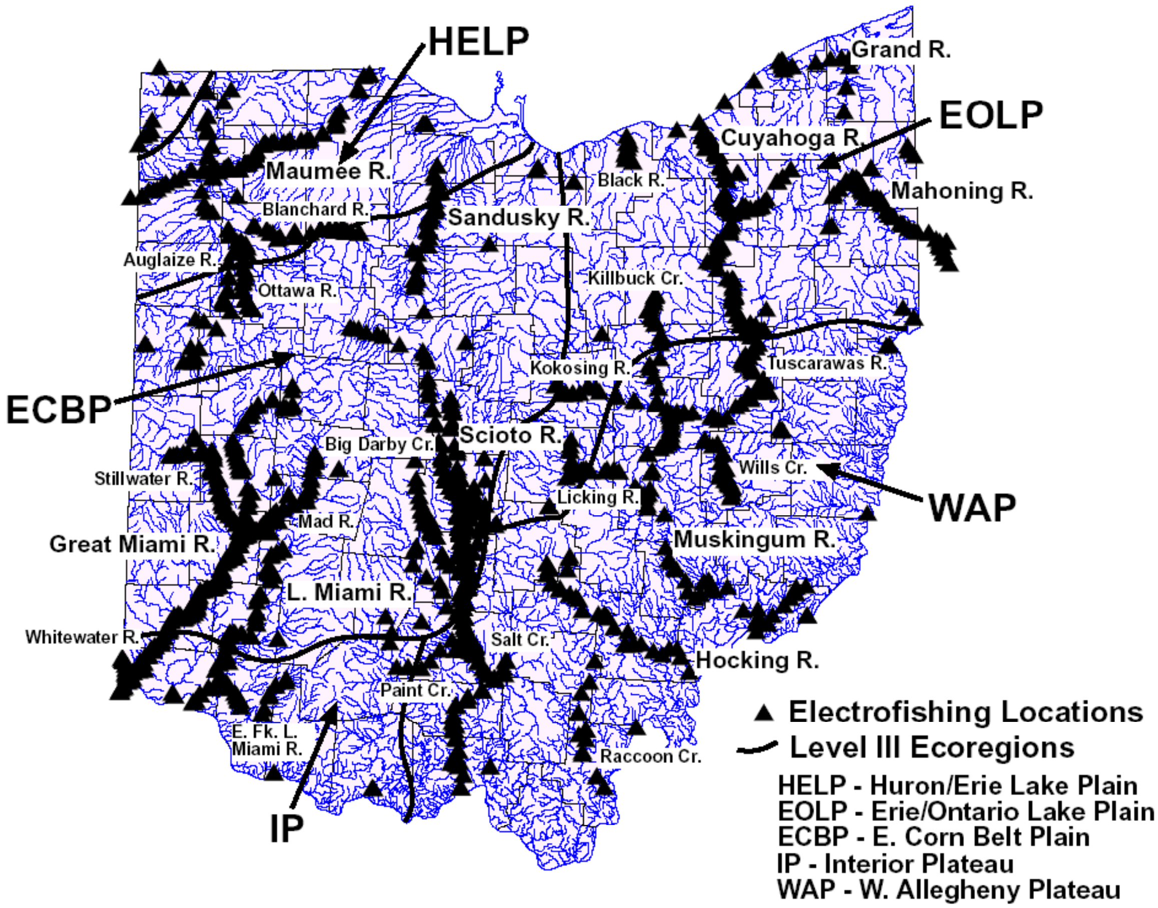


Figure 17. Ohio EPA non-wadeable fish assemblage locations sampled between 1979-2001 based on an intensive survey design.

The biological response signatures from the Scioto and Ottawa Rivers[3] (northwestern Ohio) demonstrate differential responses, non-toxic in the Scioto River and toxic in the Ottawa River, but also varying degrees of response through time (Figure 21). The Scioto River represents a situation with an absence of significant toxic impacts whereas the Ottawa River is substantially impacted by a variety of toxic stressors including legacy pollution from both abandoned and active sources. This is an example of how the component metrics and data from biological assemblage assessments can be used to accurately characterize and diagnose impacts. However, monitoring design is a critical element of building the database needed to make these types of data interpretations.

[3] The Ottawa River has a similar municipal/urban and land use setting as the Scioto River, but has two large industrial sources with a variety of legacy toxic pollutants discharged over many decades.

The intensive survey design provides a spatially intense and robust assessment of status and trends in a specific river or stream reach. Such a design is critical in making causal linkages with water quality management programs such as NPDES permitting and site-specific water quality standards issues such as designated uses and use attainability analyses. It also supports more refined 303d listings. Its value to the TMDL process additionally includes causal associations and local scale concerns such as the appropriate designation of individual waterbodies via the UAA process. There are important questions about how well this design can support broader assessment needs such as regional and statewide 305b reporting. It frequently is a matter of aggregating such data to a statewide or regional scale, but also ensuring that the design essentially represents a census of the resource. This design most effectively satisfies a critical need in water quality management, i.e., conducting monitoring and assessment at the same scale at which water quality management decisions are made.

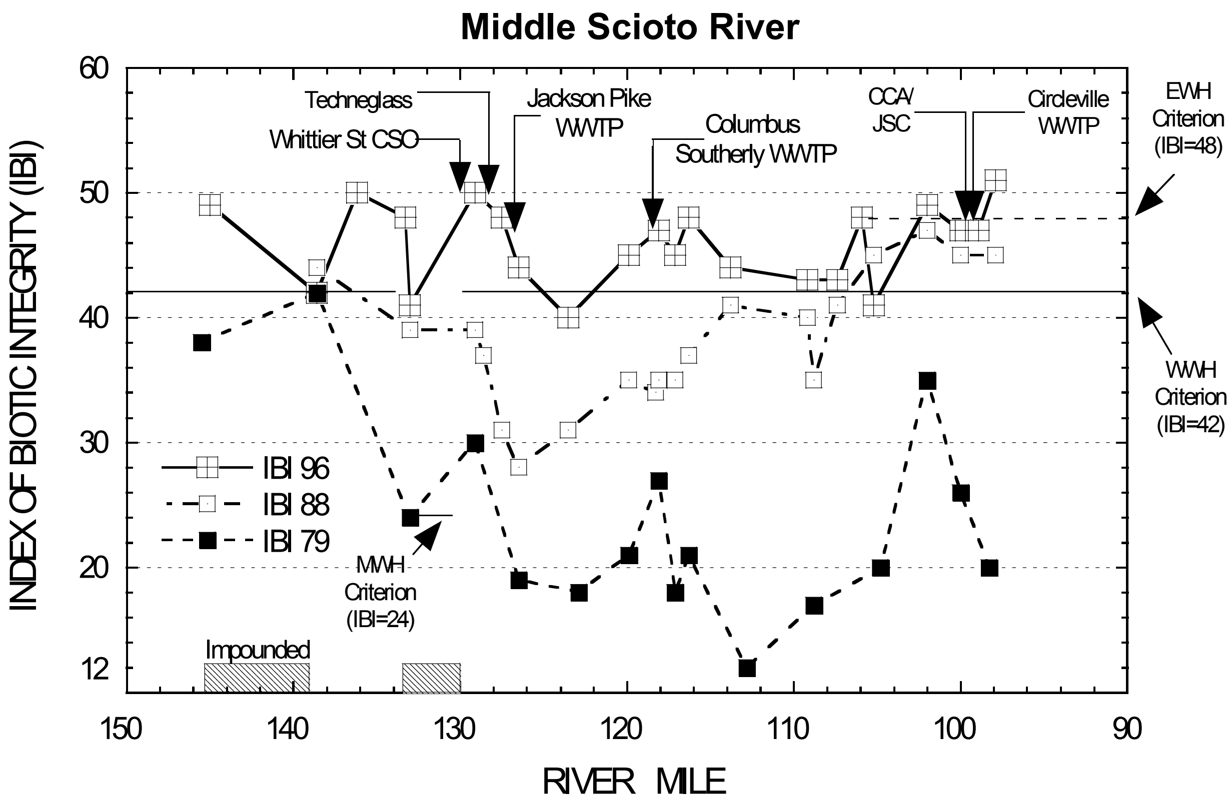


Figure 18. Longitudinal results of fish (IBI) assemblage assessments in the Scioto River based on sampling conducted in 1979, 1988, and 1996.

Option 4 – Geometric Sampling Design

The geometric sampling design was first developed by Ohio EPA (1999) and is applied to small watersheds at the 11 to 14-digit HUC size. Sampling sites are located by geometrically working "downwards" from the drainage size of the entire watershed to a resolution of 1-2 square miles of drainage area. For example, for a watershed with a drainage area of 152 square miles, one site is located at the mouth of the mainstem stream or river (152 mi^2 location), one site is located at the 76 mi^2 location, and sites are located at the 36 mi^2 locations, the 18 mi^2, 9 mi^2, 4.5 mi^2, 2 mi^2, and 1 mi^2 locations, respectively (Figure 22). Sampling sites are located at reasonable access points and

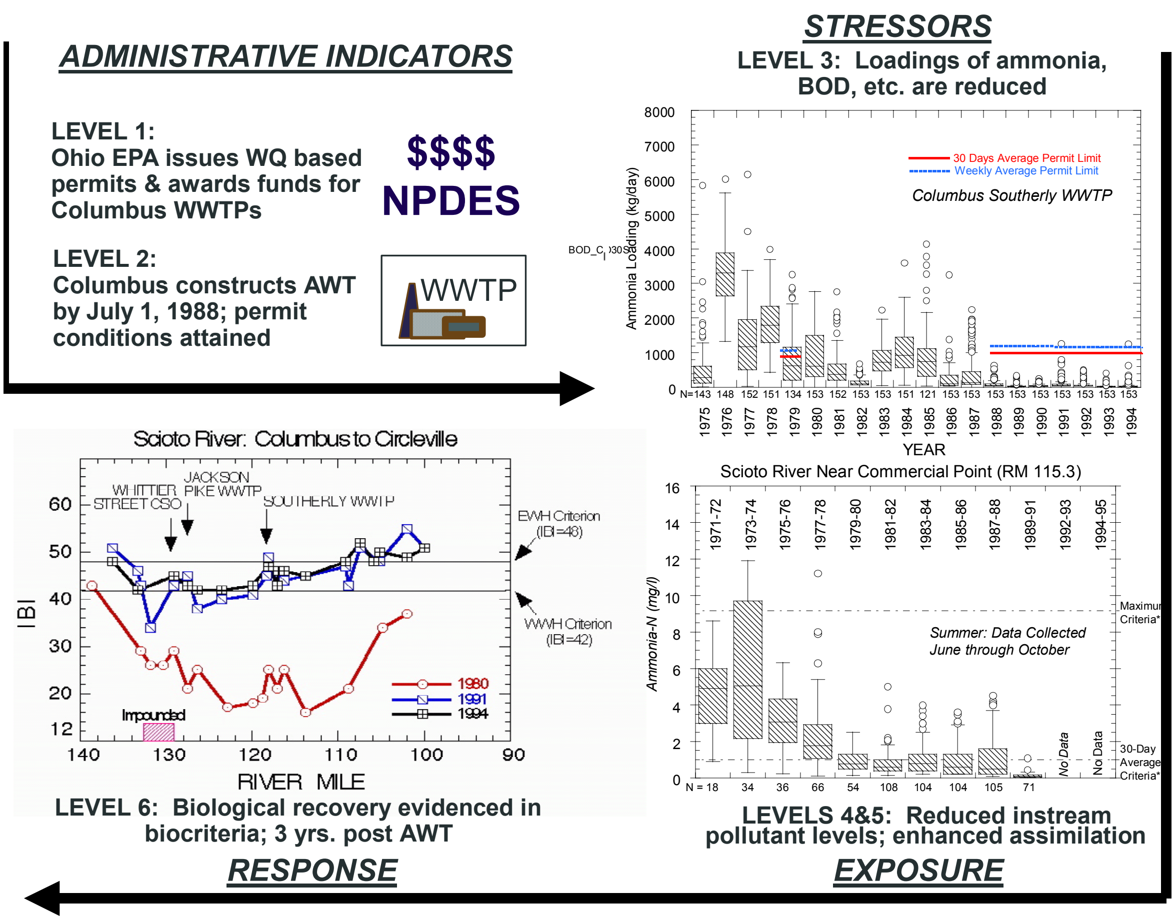
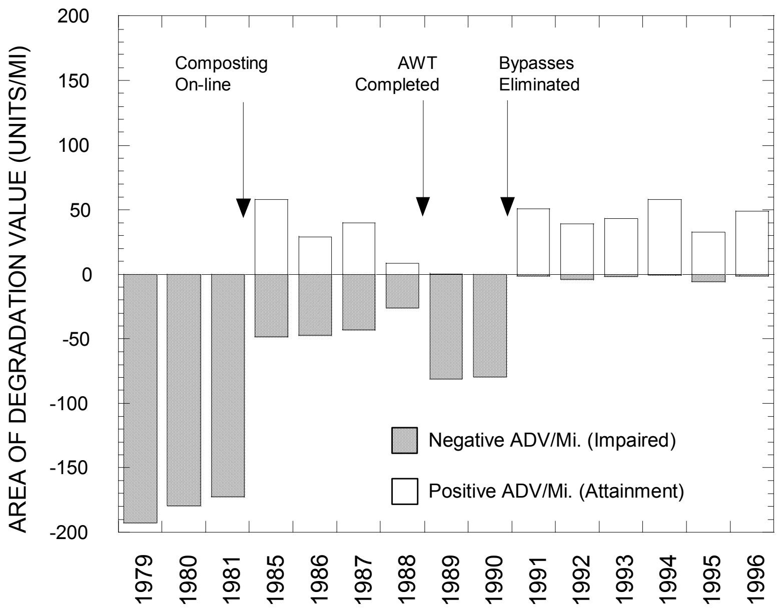


Figure 19. Using indicators based on different monitoring designs to demonstrate water quality management effectiveness by making linkages between administrative (upper left), stressor (upper right), exposure (lower right), and response indicators (lower left). This example uses the middle Scioto River mainstem and the Columbus Southerly WWTP based on data collected during 1975-1996.

with respect to tributary confluences and other factors. Gaps in coverage for specific sources or sections of interest are addressed by blending aspects of the intensive survey design as needed to ensure the adequate capture of all local scale issues.

The purpose of this design is to provide a stratified sampling of *all* streams within a watershed at a local scale of resolution. This resolution satisfies water quality management needs such as TMDL listing and development, identification of individual stream management issues, site-specific WQS issues such as designated uses and use attainability analyses, and the ranking and prioritization of management issues within a specific watershed area. While Ohio EPA has used the results to



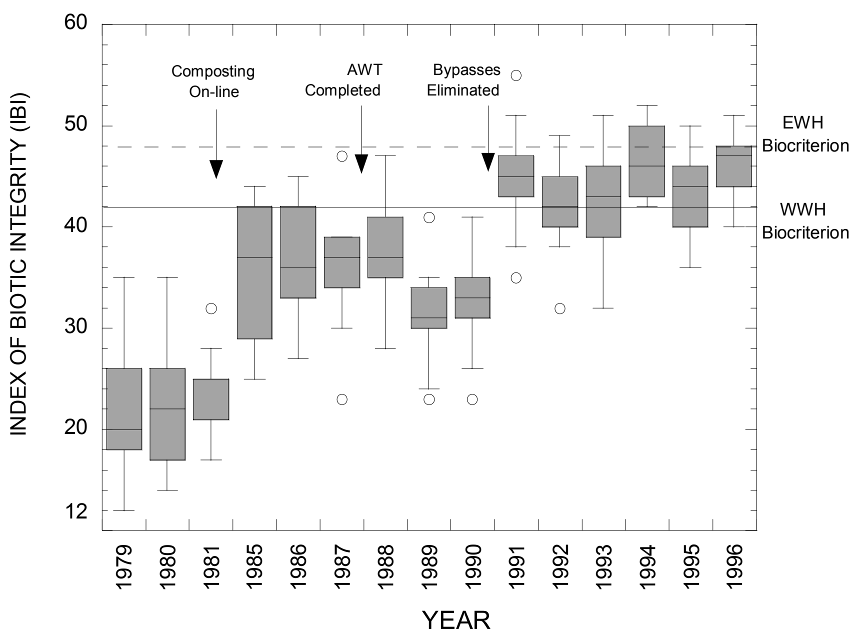
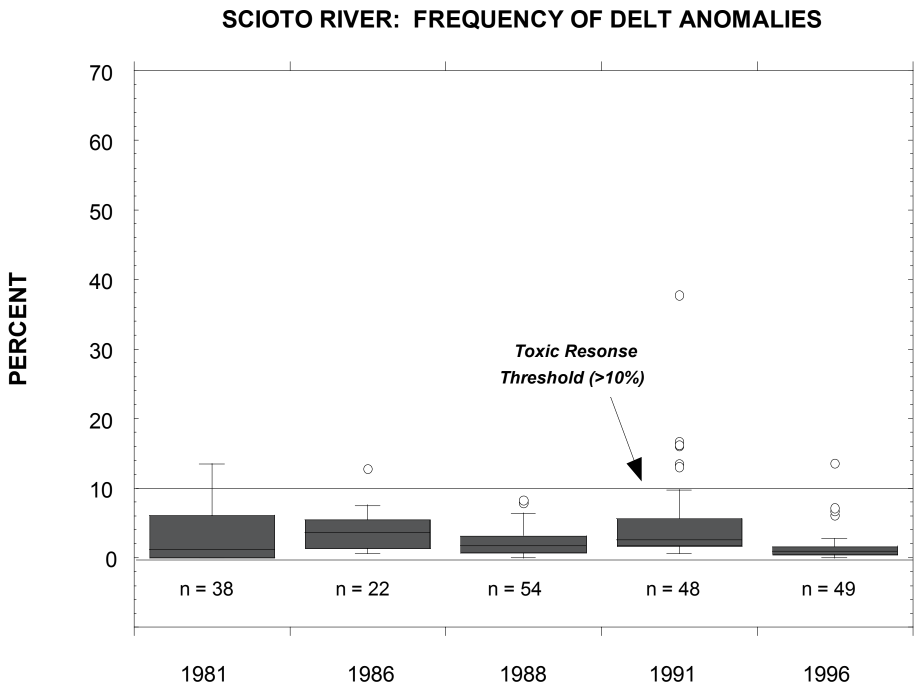


Figure 20. Annual Index of Biotic Integrity (IBI) results from the mainstem Scioto River directly impacted by municipal sewage discharges and urban runoff from Columbus, Ohio between 1979 and 1996 (lower panel; WWH = Warmwater Habitat; EWH = Exceptional Warmwater Habitat) and Area of Degradation Value (ADV) based on IBI results from the same segment and time period (upper panel). Significant changes in the operation of the sewage system are noted on each panel.



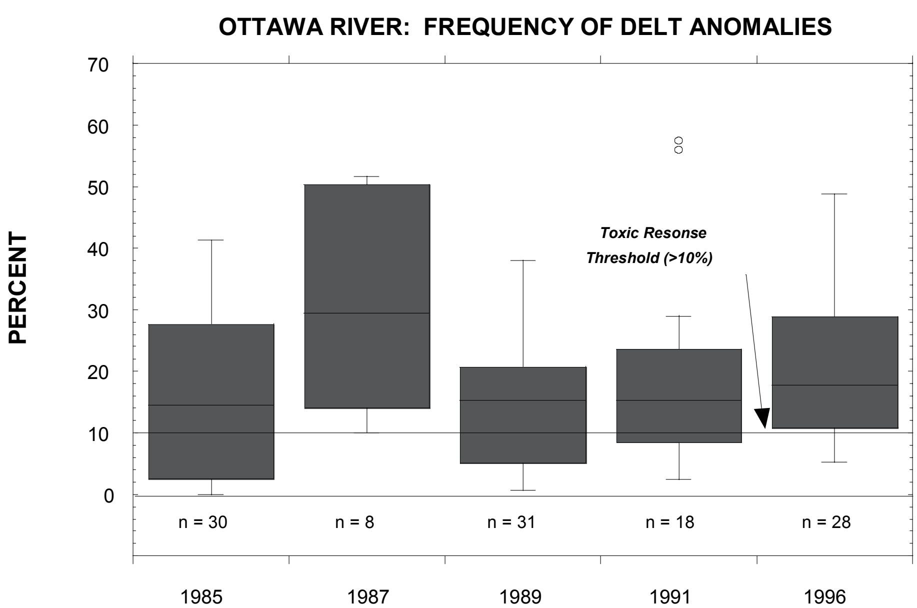


Figure 21. Examples of aggregate changes in a key fish assemblage response signature (%DELT anomalies) in the middle Scioto and Ottawa Rivers, Ohio, based on intensive survey data collected from multiple years (after Yoder and DeShon 2003).

conduct routine water quality management support activities such as stream use designations, use attainability analyses, permitting, planning, and other regulatory issues, the strength of this design is clearly with TMDL development and watershed planning support. The resulting assessment provides an initial clarification and refinement of WQS issues along with impaired waters listings that include an assessment of associated causes and sources (Figure 23). In this example, the geometric design provides a robust coverage of the watersheds that reveals patterns in stressors that correspond to clusters of streams either by size class, geographic position, or biological quality. This promotes the improved targeting of restoration, protection, and allied management efforts that are needed to implement TMDLs. This design also permits the broader comparison of whole watersheds across ecoregions and larger areas.

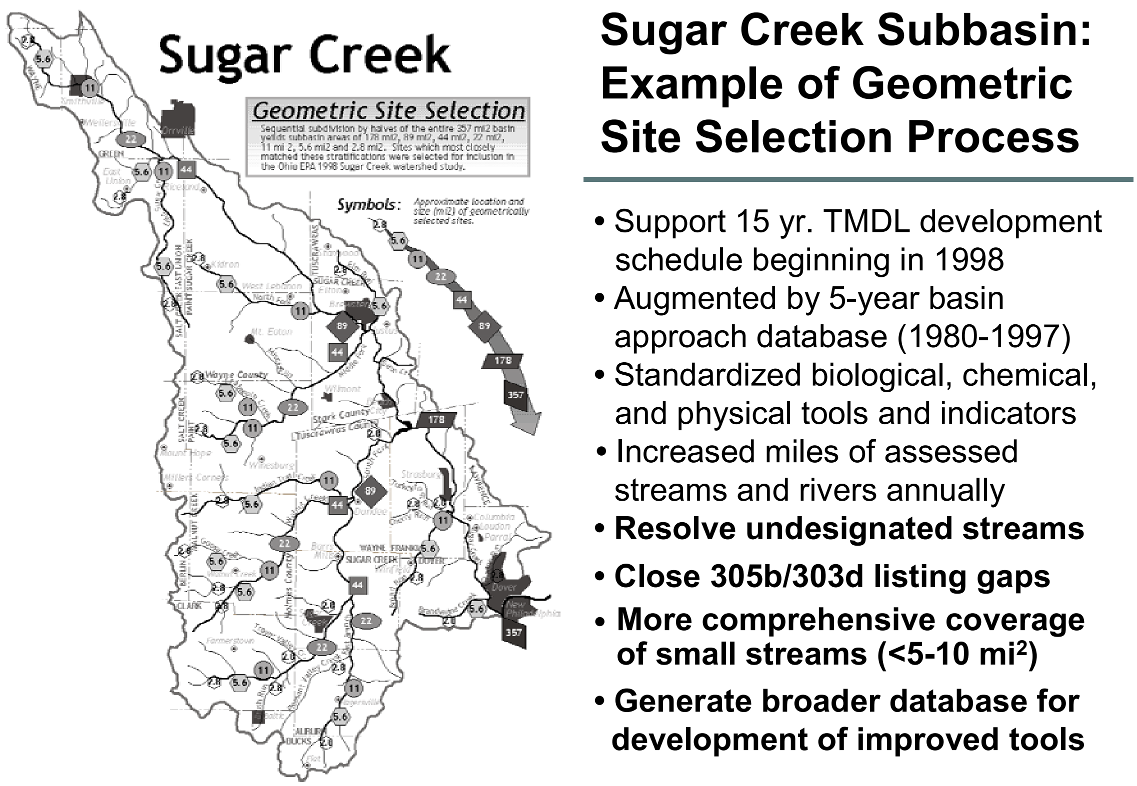


Figure 22. Geometric site selection design developed by Ohio EPA for the intensive assessment of watersheds in support of TMDL development and allied water quality management needs.

The results of selected geometric watersheds was compared to the 1995 Regional EMAP results and showed that some watersheds exhibited better or worse quality than the overall ecoregion condition revealed by the REMAP design (Figure 24). Knowing where these watersheds "fit" within the region and state coupled with the more detailed knowledge of associated stressors is of value not only to the TMDL process, but to water quality management in general. These are critical prerequisites to accurate and comprehensive TMDL development at a sufficiently detailed scale of management needed to be relevant to watershed issues and stakeholders. This design also provides a template for conducting progress and follow-up assessments to determine water quality management program effectiveness resulting from TMDL implementation activities. It also contributes to the better understanding of issues across different watersheds and supports the building of databases sufficient to address broader conceptual and technical issues.

Another advantage of the geometric sampling design is its flexibility. In homogeneous watersheds with little human influence or, at the opposite end of the spectrum, pervasive human influence, sampling intensity can be lessened if sites throughout the watershed yield similar biological assessments and have similar patterns of land use. In contrast, very homogenous reaches or segments can be sampled more intensively to evaluate the influence of specific sources. Whatever level of intensity is applied within a watershed, the consistency of the sampling pattern means that watersheds can be compared to each other by matching the sampling area associated with each sampling point from different basins, e.g., comparing biological index values for sites that integrate sites representing similar drainage areas (Figure 21). It can also provide initial information at a broad spatial scale. In this way, sampling functions as a screening tool for identifying subwatersheds that need additional or more intensive sampling in support of management applications.

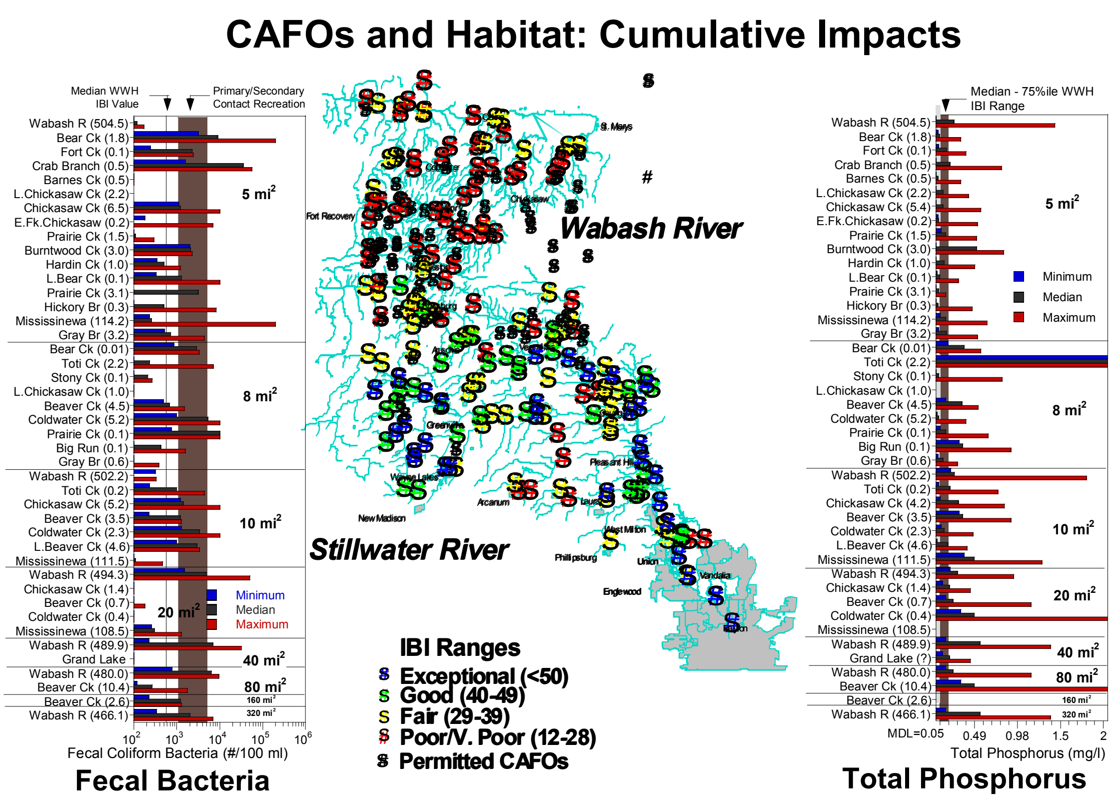


Figure 23. Fish assemblage quality by narrative range based on IBI values in the Stillwater and Wabash River watersheds based on a geometric site selection design. Corresponding stressor indicators for fecal bacteria and total phosphorus reveal spatial patterns associated with exceedences of biologically-based and water quality thresholds.

A perceived disadvantage of this design is that it requires a commitment to sampling tens or perhaps more than one hundred sites per year. If this level of sampling is not maintained, the design breaks down to an intensive sampling design from which it is difficult to extract data for broader status and trend monitoring. A major strength is that it is applied similarly to each and every watershed. If implemented in an ongoing and consistent manner (i.e., via a five year rotating basin approach) this design represents a census of all rivers and streams within the rotation time frame. Because a similar level of intensity is applied to each watershed, conditions can be summarized and compared across watersheds. Because all sites within all watersheds are

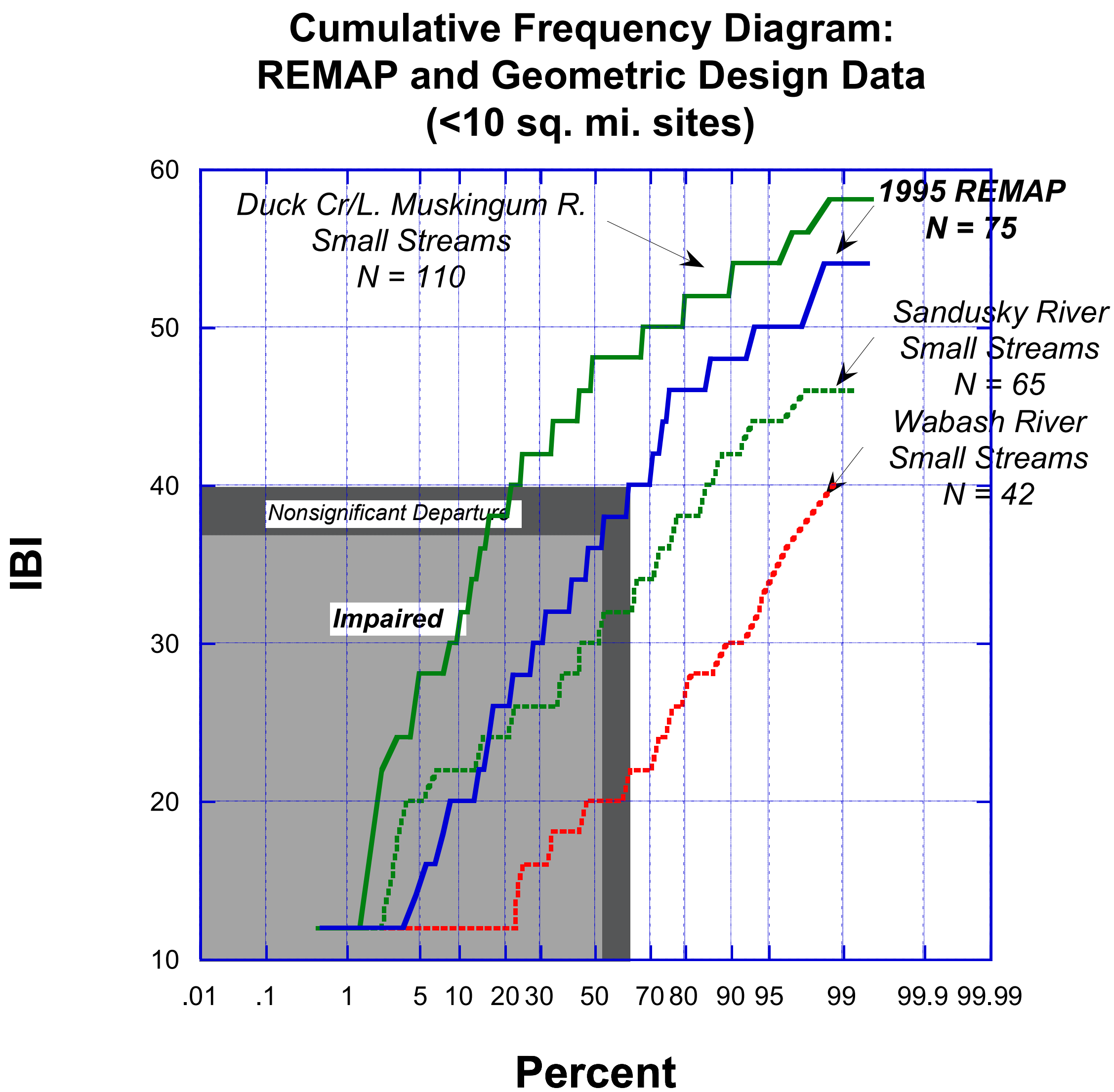


Figure 24. Cumulative frequency diagram (CFD) of fish assemblage IBI values at REMAP probabilistic sites sampled in 1995 compared to geometric sites from the Duck Creek and L. Muskingum watersheds (1999), the upper Sandusky River watershed (2000), and the Wabash River watershed (1999) in Ohio.

sampled, this approach represents a type of census design. Consequently, generalizing (or inferring) the results to the unsampled population is not an issue because a census is obtained. The implicit assumption is that the spatial coverage truly represents biological condition upstream of sampling points and that site selection within the watersheds is unbiased. Within a watershed, sites that represent specific classes of watershed size are sampled for each rotation, therefore, the results can be compared as a group through time using regression analysis to test for change (trend) in watersheds or aggregations of multiple watersheds (regions). Local scale sampling can also be accomplished to compare specific locations or evaluate changes through time. Because representative sites are sampled every five years, this design includes some of the preferred aspects of a fixed sampling design. Although sites are not sampled randomly, the geometric sample selection process is an unbiased approach to selecting sites because the same mathematical algorithm is applied to each watershed. Therefore, this approach represents an unbiased method of delineating a continuous resource and then censusing the entire population of all sampling units.

Option 5 – Probabilistic Sampling Design

Probabilistic designs include those commonly employed by the U.S. EPA Environmental Monitoring and Assessment Program (EMAP). All the potential sampling areas within a region of interest are identified, segmented and enumerated; segments are randomly selected and sites are sampled within the selected segments (Stevens and Olsen 1999). This design assumes that the resource is simply too large to visit every site (i.e., accomplish a census); therefore, a set of samples are randomly selected to represent the entire population. Results from the random sampling can be used to infer the condition of the entire resource, including segments and sites that were not sampled. This sampling design was developed to answer questions related to the status and trends of water resources at regional and national scales of resolution.

To date, three EMAP pilot projects have been implemented for surface waters across the U.S. These projects sampled large regional areas that included sites from several states in the Northeastern, Mid-Atlantic, and intermountain West. In addition, numerous Regional EMAP (REMAP) programs have been conducted at regional scales, typically involving parts of one or two states. Other efforts have been conducted with individual states and the IDEM probabilistic design serves as an example (Figure 25). An advantage of a probabilistic design is that comparatively large-scale changes can be recognized more quickly than with other types of designs. The results of the regional assessment are also unbiased due to random sampling. This means that the results obtained by sampling a subset of sites will truly be representative of regional conditions.

There are two principal disadvantages to this approach for states that are interested or obligated to assess beyond status. First, to obtain a random sample, every aquatic resource of concern must be delineated. Second, specific sites of management interest cannot be included in probabilistic sampling designs unless they are randomly chosen. Thus, information about individual sites is potentially excluded because the conclusions made at the regional scale cannot necessarily be attributed to specific sites or individual water bodies. This is one of the principal trade-offs between probabilistic sampling and intensive scale sampling.

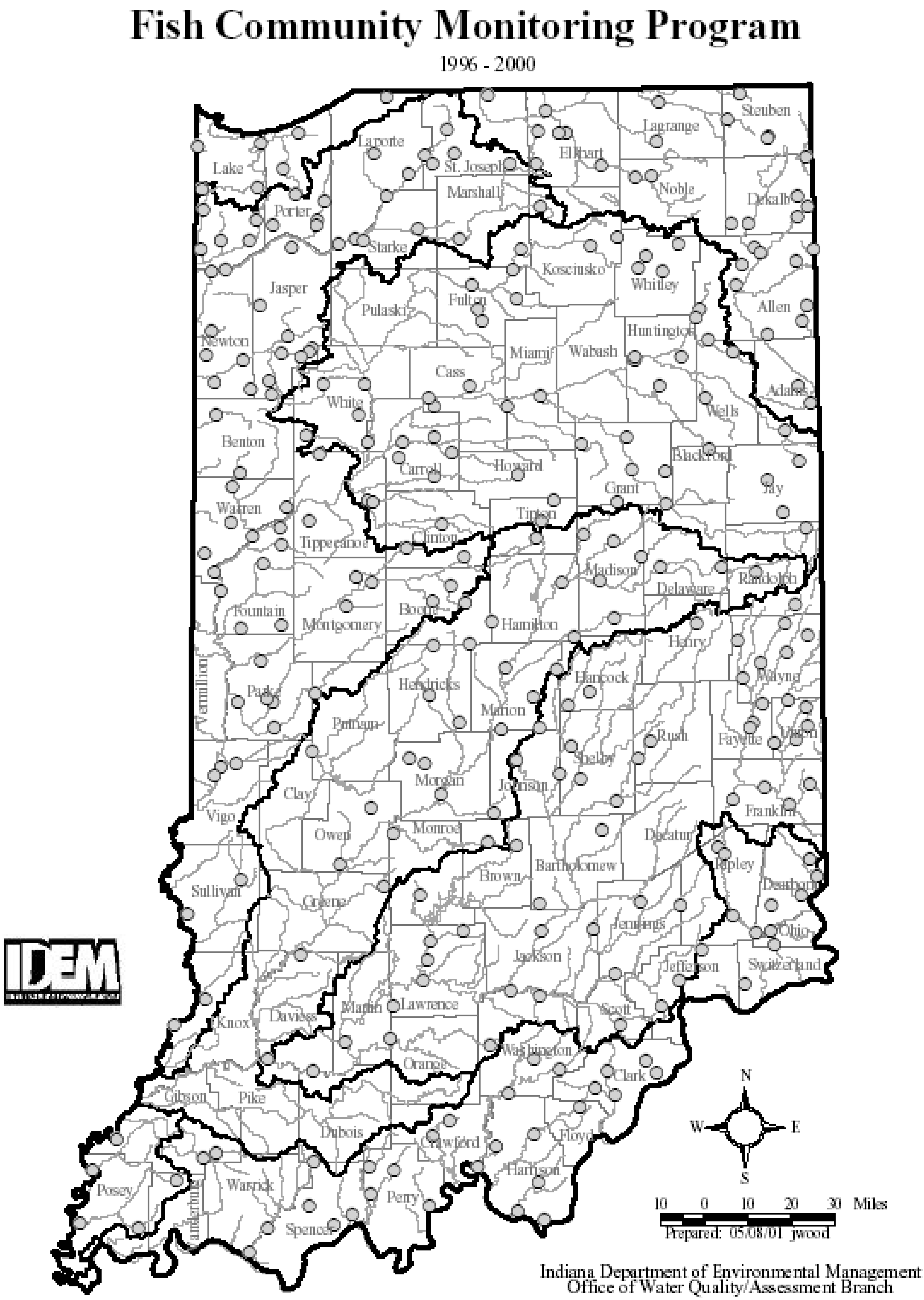


Figure 23. Probabilistic design employed by Indiana DEM to assess fish assemblage condition.

Some states have dealt with this trade-off and by using probabilistic sampling for primary site selection, but reserving a certain percentage of the annual sampling budget for more intensive, targeted sampling. Broad-scale probabilistic sampling is used to identify "hot spots", or areas of specific interest due to high or poor biological condition or other unusual conditions. In terms of state-specific uses of this approach, the recently completed REMAP project in the E. Corn Belt Plains (ECBP) ecoregion of Indiana, Ohio, and Michigan provides some insights. The fish assemblage data obtained from one year of probabilistic sampling was compared to three years of intensive watershed sampling using a targeted, census design in the same ecoregion (Figure 24). IBI results were compared using a cumulative frequency diagram analysis, which showed some differences between the REMAP results and single years of the intensive, census based sampling. However, when the three years of intensive survey design were aggregated, the median IBI was

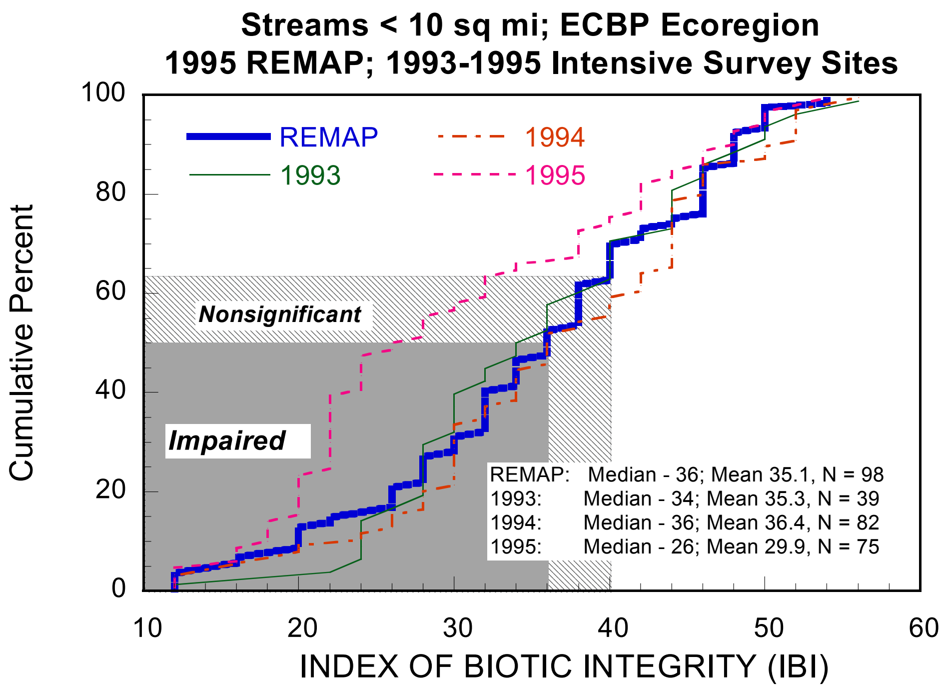


Figure 24. Cumulative frequency diagram (CFD) showing results of fish assemblage IBI based on the 1995 E. Corn Belt Plains REMAP project and three years (1993-1995) of intensive survey results from the same ecoregion and similar size streams. Shaded areas represent impaired and nonsignificant departure from the ecoregion IBI biocriterion.

nearly identical to the REMAP results. While this brief comparison does not address all of the issues between the different designs, it illustrates the ability to demonstrate important scale differences while achieving a similar assessment of overall status between different designs. The strength of the probabilistic approach is that broad, regional assessments of status and trend can be achieved in a comparatively brief time period and with fewer sampling locations than with intensive surveys. Intensive surveys, however, deliver essential local and stream specific information that is of direct interest to water quality management programs and which is not delivered by the common probability designs.

Implications to Water Quality Management Support

The choice of which spatial design(s) to employ in a multifaceted and comprehensive monitoring and assessment program should include considerations of all activities and programmatic objectives that must be satisfied by the same datasets. If the need is to report on trends through time irrespective of other programs and activities, then a probabilistic design seems to satisfy that need in the most timely and statistically robust manner. However, given the reality that states have other equally important water quality management objectives and programs to support, all of which would benefit from improved monitoring outputs and outcomes, consideration of more than one spatial design is appropriate. This was conceptually recognized by the EPA CALM process (U.S. EPA 2003) and we prepared Table 3 to aid in this process. Thus selecting a particular design or set of designs entails knowing how each can be used in a complementary manner to satisfy all water quality program needs.

The relative capability of each of the five designs to support various aspects of water quality management is described in Table 3. No single design supports all water quality management program areas equally well. Some designs are inherently better for supporting status and trends at regional or statewide scales, while other designs are better suited to support site and stream/river specific water quality management. Table 3 attempts to compare how effectively each of the designs considered by this report support the water quality management program areas that are in common to state water quality management agencies. The goal should be to select a sampling design or set of designs that support *all* state water quality management needs *with the same datasets and in the most cost-effective manner.* Another important consideration is ensuring that monitoring and assessment is conducted at the same scale at which water quality management takes place. For this consideration, an intensive sampling design such as the geometric design is probably more appropriate than the probabilistic design, although probabilistic sampling could be conceivably applied at a subwatershed scale. The attributes and capabilities of the different sampling designs can be compared and screened for their relevance for different monitoring goals using Table 3.

Table 3 is based on the collective experiences gained by selected states and some EPA Regions in using ambient monitoring data to support different water quality management programs. Some of this is based on the preceding discussion and description of the five major spatial monitoring designs. In terms of satisfying the objective of assessing spatial and temporal trends a probabilistic design would satisfy the overall assessment needs posed by 305b and similar programs in the shortest length of time. However, given the realities of overlapping and simultaneous water quality and natural resource management programs, a geometric and/or intensive survey design will be needed. If a probabilistic sampling design is selected for trends, a certain percentage of sites must be sampled each year outside of this framework to support other programs. While it takes longer for these designs to accumulate sufficient data and information to develop adequate trend information, the payoff is in the other management support functions, some of which are pressing needs accentuated by the recent emphasis on TMDLs. Resources will also dictate how quickly this information is accumulated; in the best situations this may well involve a 10 year process before sufficient trend information becomes available. The goal should be to have a monitoring and assessment design that satisfies multiple and diverse water quality management programs in the

Table 3. Relative degrees to which major water quality management program areas are supported by different spatial and temporal monitoring designs.

Design	Basic Reporting		WQS Program					Watersheds/ NPS		TMDL/303d		NPDES/Other Permitting							
Type of Design[1]	Status[2]	Trend[3]	Tiered Uses[4]	UAA[5]	Refined WQC[6]	Anti-deg.	Site-Specific Crit.Mod.[7]	NPS/BMP Effective-ness	Hab-itat[8]	List/ Delist	TMDL Dev.[9]	WQ BELs[10]	Priority Setting [11]	CSOs/ SSOs	Storm-water Ph. I&II	WET Limits/ Cond.[12]	Sever-ity/ Extent[13]	Enforce ment[14]	404/401 Dredge & Fill[15]
Fixed Station	○	○	–	–	–	–	–	○	○	–	○	○	–	○	–	–	–	–	–
Synoptic Watershed	◐	◐	○	○	○	○	○	○	○	○	○	○	○	–	–	–	–	–	–
Intensive Survey	◐	◐	●	●	●	●	●	●	●	●	●	●	◐	●	●	●	●	●	●
Probaba-listic: Regional	◐	◐	–	–	◐	–	–	◐	◐	○	–	–	–	–	–	–	◐	○	–
Probaba-listic: Watershed	●	●	◐	○	◐	◐	○	●	◐	◐	◐	○	◐	◐	◐	–	◐	○	–
Geometric Watershed	●	●	●	●	●	●	◐	●	●	●	●	◐	●	●	●	◐	●	●	●

● - Comprehensively fulfills program support role by providing robust and complete assessment of program needs and issues including scientific certainty and accuracy of condition assessment.
◐ - Generally fulfills program support, but may not provide sufficiently robust or accurate assessment information at all scales or for overall assessment of magnitude and severity.
○ - Supports only partial or indirect assessment of program area, e.g., may be useful only for pollutant-specific assessment at a single scale.
– Cannot support program needs due to incomplete spatial coverage, connectivity, or inadequate resolution at the equivalent scale of management.

---

[1] Design types are inherently generic; modified and hybrid approaches are possible and will encumber the attributes and characteristics of each generic design.
[2] Basic attainment/non-attainment assessment for aquatic life use status including delineation of causes and sources of threat and impairment.
[3] Sufficient information to report aggregate status within specific ecotypes over at least a 10 year period including all sources and causes of impairment at all relevant scales of management.
[4] Tiered uses that are developed based on assemblage assessments and which correspond to EPA's biological condition axis; does not include generic fishery based or general uses.
[5] Includes any use of ambient monitoring data to change designated uses on a site-specific or waterbody specific scale.
[6] Design results in the aggregate accumulation of data that is used to influence the application or implementation of WQC (exclusive of pH, hardness, and other single parameter modifiers).
[7] Yields sufficiently detailed ambient data that is used to ground truth EPA's site specific criteria process (water effects ratio).
[8] Monitoring design is sufficient to assess habitat at both local, reach, and watershed scales and develop habitat relationships with biological condition to support tiered use implementation.
[9] Includes using ambient data to support TMDL development and determine success of TMDL implementation beyond basic calibration data.
[10] Water quality based effluent limits – reach-specific monitoring data is used to develop an assessment of the overall effect of the subject discharge on the receiving waters.
[11] Ambient monitoring data is used to influence priority setting for various water quality management program needs (e.g., NPDES permitting and/or SRF funding priorities) at all relevant scales..
[12] Ambient monitoring data is sufficiently detailed to influence WET testing requirements and/or effluent limits in NPDES permits.
[13] Monitoring design and assessment framework allows for determination of incremental departures and changes beyond pass/fail and communicates severity of problem over space & time.
[14] Monitoring design supports site-specific and/or case specific enforcement in terms of demonstrating that the action is both legal and reasonable.
[15] Direct support of site-specific decisions for the 401 certification of 404 dredge and fill permits.

most accurate, comprehensive, and cost-effective manner possible. This means adhering to the principal concepts and guidance of adequate monitoring and assessment, as described in this report. The desired outcome will be two fold; 1) watershed level monitoring that routinely deliver data, information, and assessments that support baseline water quality management program needs (i.e., reporting, WQS, permitting, and planning), and 2) the development and custody of a long term database comprised of an adequate array of chemical, physical, and biological indicators. This means that at the individual watershed study unit level, monitoring and assessment supports developing an integrated assessment of status and limiting factors, WQS (use attainability analyses, improved criteria and thresholds), permitting, watershed planning, and restoration activities. While this information satisfies what may be termed "day-to-day" management needs, the ongoing execution of the monitoring and assessment program also produces a database that has unique value for making ongoing improvements to all water quality management support functions such as regional reference condition, criteria development, indicator development, and the assessment and modification of policies, practices, and legislation. In other words monitoring and assessment, if it is conducted as a routine cost of doing business, will deliver more of value than the determination of status and individual watershed assessments. However, it must be maintained as an ongoing and baseline activity that is an integral part of the overall water quality management strategy if it is to accomplish these important functions.

References

Bartsch, A.F. 1948. Biological aspects of stream pollution. Sewage works journal, 20 (1948): 292-302.

Benke, A.C. 1990. A perspective on America's vanishing streams. J. N. Am. Benth. Soc., 9 (1): 77-88.

Cooly, J.L. 1976. Nonpoint pollution and water quality monitoring. J. Soil Water Cons., March-April: 42-43.

Courtemanch, D. L. 1995. Merging the science of biological monitoring with water resource management policy: criteria development, pp. 315-325. in W. S. Davis and T. P. Simon (eds.). Biological assessment and criteria: tools for water resource planning and decision making. Lewis Publ., Boca Raton, Fla.

Doudoroff, P. and C.E. Warren. 1951. Biological indices of water pollution with special reference to fish populations, pp. 144-153. Biological Problems in Water Pollution, U.S. Public Health Service, Robt. A. Taft Sanitary Engineering Center, Cincinnati, OH.

General Accounting Office (GAO). 2000. Water quality – key EPA and state decisions are limited by inconsistent and incomplete data. GAO/RCED-00-54. Washington, DC: GAO.

General Accounting Office (GAO). 2003a. Major Management Challenges and Program Risks: Environmental Protection Agency. GAO-03-112. Performance and Accountability Series. US General Accounting Office, Washington, DC.

General Accounting Office (GAO). 2003b. Water quality: improved EPA guidance and support can help states develop standards that better target cleanup efforts. GAO-03-308, U.S. General Accounting Office, Washington, D.C.

Indiana Dept. of Environmental Management (IDEM). 2001. Surface water quality monitoring strategy - revised. IDEM 32/01/013/1998 rev. 2001. Offc. Of Water Mgmt., Assessment Branch, Surveys Section. Indianapolis, IN. 158 pp.

Indiana Dept. of Environmental Management (IDEM). 1998. Indiana fixed station statistical analysis 1997. IDEM 32/02/005/1998. Offc. Of Water Mgmt., Assessment Branch, Surveys Section. Indianapolis, IN. 105 pp.

ITFM (Intergovernmental Task Force on Monitoring Water Quality). 1995. The strategy for improving water-quality monitoring in the United States. Final report of the Intergovernmental Task Force on Monitoring Water Quality. Interagency Advisory Committee on Water Data, Washington, D.C. + Appendices.

ITFM (Intergovernmental Task Force on Monitoring Water Quality). 1993. Ambient water quality monitoring in the United States: second year review, evaluation, and recommendations. Interagency Advisory Committee on Water Data, Washington, D.C. + Appendices.

ITFM (Intergovernmental Task Force on Monitoring Water Quality). 1992. Ambient water quality monitoring in the United States: first year review, evaluation, and recommendations. Interagency Advisory Committee on Water Data, Washington, D.C.

Judy, R. D., Jr., P. N. Seely, T. M. Murray, S.C. Svirsky, M. R. Whitworth, and L.S. Ischinger. 1984. 1982 national fisheries survey, Vol. 1. Technical Report Initial Findings. U.S. Fish and Wildlife Service, FWS/OBS-84/06.

Karr, J.R. and C.O. Yoder. 2004. Biological assessment and criteria improve TMDL planning and decision-making. Journal of Environmental Engineering (in press).

Karr, J. R., and Chu, E. W. 1999. Restoring life in running waters: better biological monitoring. Island Press, Washington, D.C.

Karr, J. R. 1991. Biological integrity: a long-neglected aspect of water resource management. Ecological Applications 1: 66–84.

Karr, J. R., K. D. Fausch, P. L. Angermier, P. R. Yant, and I. J. Schlosser. 1986. Assessing biological integrity in running waters: a method and its rationale. Illinois Natural History Survey Special Publication 5: 28 pp.

Karr, J. R., and Dudley, D. R. 1981. Ecological perspective on water quality goals. Environ. Management 5: 55–68.

Lyons, John, R.R. Piette, and K.W. Niermeyer. 2001. Development, validation, and application of a fish-based index of biotic integrity for Wisconsin's large warmwater rivers. Transactions of the American Fisheries Society: Vol. 130, No. 6, pp. 1077–1094.

National Research Council (NRC). 2001. Assessing the TMDL Approach to Water Quality Management. National Academy Press, Washington, DC., 109 pp.

National Research Council (NRC) 2000. Ecological Indicators for the Nation. Washington, DC: National Academy Press. http://www.nap.edu/catalog/9720.html.

Ohio Environmental Protection Agency. 1999. Ohio EPA Five-Year Surface Water Monitoring Strategy: 2000–2004. Ohio EPA Technical Bulletin MAS/1999-7-2. Division of Water Quality Monitoring and Assessment, Surface Water Section, Columbus, Ohio.

Rankin, E. T., and Yoder, C. O. 1990. A comparison of aquatic life use impairment detection and its causes between an integrated, biosurvey-based environmental assessment and its water column chemistry subcomponent. Appendix I, Ohio Water Resource Inventory (Volume 1), Ohio EPA, Div. Water Qual. Plan. Assess., Columbus, Ohio.

Stevens, D.L. and Olsen, A.R. 1999. Spatially restricted surveys over time for aquatic resources. J. Ag. Biol. Environ. Stat. 4: 415-428.

The Heinz Center. 2002. The State of the Nation's Ecosystems, Measuring the Lands, Waters, and Living Resources of the United States. New York, NY: Cambridge University Press. http://www.heinzctr.org/ecosystems.

U.S. Environmental Protection Agency. 2003. Elements of a state monitoring and assessment program. EPA 841-B-03-003. Office of Water, Washington, DC. 14 pp.

U.S. Environmental Protection Agency. 1995a. Environmental indicators of water quality in the United States. EPA 841-R-96-002. Office of Water, Washington, DC 20460. 25 pp.

U.S. Environmental Protection Agency. 1995b. A conceptual framework to support development and use of environmental information in decision-making. EPA 239-R-95-012. Office of Policy, Planning, and Evaluation, Washington, DC 20460. 43 pp.

U.S. Environmental Protection Agency. 1994. Section 106 and 604[b] grant guidance - water monitoring. U.S. EPA, Office of Water, Assessment and Watershed Protection Division, Washington, DC. 9 pp. + app.

U.S. Environmental Protection Agency. 1991a. Environmental monitoring and assessment program. EMAP - surface waters monitoring and research strategy - fiscal year 1991, EPA/600/3-91/022. Office of Research and Development, Environmental Research Laboratory, Corvallis, OR. 184 pp.

U.S. Environmental Protection Agency. 1990. Feasibility report on environmental indicators for surface water programs. U. S. EPA, Office of Water Regulations and Standards, Office of Policy, Planning, and Evaluation, Washington, D. C.

Yoder, C.O. and J.E. DeShon. 2003. Using Biological Response Signatures Within a Framework of Multiple Indicators to Assess and Diagnose Causes and Sources of Impairments to Aquatic Assemblages in Selected Ohio Rivers and Streams, pp. 23-81. *in* T.P. Simon (ed.). BIOLOGICAL RESPONSE SIGNATURES: patterns in biological integrity for assessment of freshwater aquatic assemblages. Lewis Publishers, Boca Raton, FL.

Yoder, C.O. 1998. Important Concepts and elements of an adequate state watershed monitoring and assessment program, pp. 615-628. *in* Proceedings of the NWQMC National

Conference Monitoring: Critical Foundations to Protecting Our Waters. U.S. EPA, Washington, DC, 663 pp. + app.

Yoder, C.O. and E.T. Rankin. 1998. The role of biological indicators in a state water quality management process. Env. Mon. Assess. 51(1-2): 61-88.

Yoder, C.O. and E.T. Rankin. 1995a. Biological criteria program development and implementation in Ohio, pp. 109-144. in W. Davis and T. Simon (eds.). Biological Assessment and Criteria: Tools for Water Resource Planning and Decision Making. Lewis Publishers, Boca Raton, FL.

Yoder, C. O., and Rankin, E. T. 1995b. Biological criteria program development and implementation in Ohio, pp. 109-144. in W. Davis and T. Simon (eds.). Biological Assessment and Criteria: Tools for Water Resource Planning and Decision Making. Lewis Publishers, Boca Raton, FL.

Yoder, C.O. 1995. Policy issues and management applications of biological criteria, pp. 327 - 344. *in* W. Davis and T. Simon (eds.). Biological Assessment and Criteria: Tools for Water Resource Planning and Decision Making. Lewis Publishers, Boca Raton, FL.